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RAILWAY CURVES - SHUNK

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A

PRACTICAL TREATISE

ON

RAILWAY CURVES

AND

LOCATION,

FOR YOUNG ENGINEERS.

CONTAINING A FULL DESCRIPTION OF THE INSTRUMENTS, THE MANNER OF ADJUSTING THEM, AND THE METHODS OF PROCEEDING IN THE FIELD,—NEW AND SIMPLE FORMULE FOR COMPOUND AND REVERSE CURVING,—RULES FOR CALCULATING EXCAVATION AND EMBANKMENT,—STAKING OUT WORK, &c., TOGETHER WITH TABLES OF NATURAL SINES AND TANGENTS, RADII, CHORDS, ORDINATES, AND OTHERS OF GENERAL USE IN THE PROFESSION.

BY

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PHILADELPHIA :

HENRY CAREY BAIRD & CO.,

INDUSTRIAL PUBLISHERS, BOOKSELLERS AND IMPORTERS,
810 WALNUT STREET.

1890.

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P R E F A C E.

THE located line for railway is a series of curves and straight lines, or tangents. These are first plotted to a large scale from data gathered on preliminary survey. It is therefore desirable that all explorations should be made with extreme care, as upon their correctness depend, in no small degree, the labour and time required in location. It were better for accuracy that all angles should be made and recorded from the plates, and the needle used only as a test, or check. Good chaining is indispensable. Great attention, too, should be given to the proper use of the slope instrument. By these means a working map can be constructed in the office upon which the proposed location, grade lines, &c., may be traced with tolerable resemblance to fact. Still many errors attach to both data and map, and these, together with the unexpected obstacles encountered in the field, require ready knowledge of the means for overcoming them.

It has been my design to present this knowledge to my younger fellows in the profession. I have endeavoured to

do it lucidly and concisely—without supposing unusual cases—without prolix proof or complex figuring. The problems given are of frequent occurrence, and the tables appended will be found useful and correct.

To STRICKLAND KNEASS, a gentleman whose professional abilities are well known, I return thanks for valuable assistance. I would likewise make my acknowledgments, for useful suggestions, to CHARLES DELISLE, an engineer of high mathematical attainment.

I am aware that much more might have been said—much more suggested—on the subject of location; but a field book being the object, the compact plan precluded any extensive essay.

If the work with brevity combines clearness, and is comprehensive withal, it is the work intended.

W. F. SHUNK.

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EXPLANATIONS.

ALL railway curves are parts of circles. They are designated *generally* from their character as simple, compound, or reverse; and *specifically* from the central angle subtended by a chord of 100 feet at the circumference, this being the length of the chain in common use. It is found that the circle described with radius of 5730 feet has a circumference of 36,000 feet. Since there are 360° in the circle, the central angle subtended by a chord of 100 feet is, in this case, equal to 1° , and the curve is named a *one degree* curve. So likewise in a circle with radius of 2865 feet, half of 5730, the central angle corresponding to the chord 100 is 2° ; the curve is then called a *two degree* curve.

The beginning of a curve is called the point of curvature, or simply the P. C., and its termination the point of tangent, marked P. T.

A compound curve is composed of two curves of different radii, turning in the same direction, and having a common tangent at their point of meeting. This point is called the point of compound curvature, or P. C. C.

A reverse curve is composed of two curves turning in different directions, and having a common tangent at their point of meeting, which latter is named the point of reversed curvature, or the P. R. C.

All sines and tangents made use of in this work are from the table at the end of the volume. For calculating curves it is not necessary to use more than four decimals.

A *Bench* is a shoulder hewn with the axe on the buttressed base of a tree, and so shaped at the top as to afford footing to the rod. The tree is blazed and the elevation of the bench marked on it with red chalk. Benches serve as permanent reference points to the level. They are placed, where it is possible, about one thousand feet apart.

Points. The operation termed pointing is the fact of putting a peg firmly into the ground, and of driving in its top a tack, or making thereon an indentation whose place is indicated by cross keel marks, directly in the line of collimation of the transit. Thus true lines are traced on the ground, and angles measured accurately. When the transit is set over a point it is so posited that the plumb hangs immediately above the tack head. If the head plate of the tripod be much inclined the plumb should be examined after levelling the instrument, as that operation disturbs it to some extent.

Stations. The line of a survey is marked on the ground at regular intervals, by stakes two feet in length, blazed, and numbered from 0 up in arithmetical progression. These stakes are named stations. On exploration they are commonly placed two hundred, and on location, one hundred feet apart.

It is customary, when locating, to drive pegs even with the surface along the true line, and to place the stations a couple of feet to the right, numbers facing in, to show their

position. The pegs are less liable to disturbance from frost, animals, &c.

In locating for construction stakes are driven on sharp curves at intervals of 50, sometimes 25 feet.

The Chain in general use for railway surveys is made of soft iron. It is 100 feet long, and divided into 100 links, each one foot in length. At every tenth link is attached a brass drop, toothed so as to indicate its distance from the end. It presents the advantages of durability, accuracy, and expedition.

A PRACTICAL TREATISE

ON

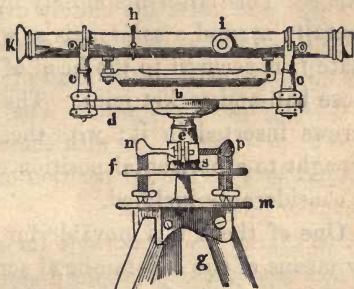
RAILWAY CURVES AND LOCATION.

ARTICLE I.

OF THE INSTRUMENTS.

THE LEVEL.

THE level is an instrument used in ascertaining the undulations of the ground along the line of a survey, and of measuring these irregularities accurately in reference to an assumed base called the datum. It consists mainly of the telescope *k i*, the spirit-level and its encasement *b*, the Y's *c c*, the rectangular bar *o d*, the axis *e*, the plates and levelling screws *f m*, and the tripod *g*.



In the tube of the telescope at *h*, and at right angles to its axis, is placed a flat ring, called the diaphragm. To this ring the cross-hairs are attached—two delicate spider lines stretched over it vertically and horizontally, and intersecting at the centre. It is held in position by four

slightly movable screws, which pierce the tube in the direction of the "cross-hairs." i is a milled head for adjusting the focus of the object glass, and k an inserted tube, containing several lenses, which may be moved out or in so as to make the spider-lines distinctly visible.

A straight line looked along from the eye glass at k through the intersection of the cross-hairs is the *line of sight*, technically named the *line of collimation*.

The immediate supports of the telescope are called the Y's, from their resemblance to that letter. If a small arch were sprung between the two legs of the Y it would give a good idea of the clasping pieces which hold the telescope in place. They are jointed to one leg and secured to the other by pins which may be withdrawn and the pieces turned back in order to remove the telescope, or change it end for end.

The Y's are attached at right angles to the bar d , which, again, is connected firmly at right angles with the hollow axis e . This latter fits closely over and is revolvable horizontally around a *solid* axis s , which, passing through the plate f , is secured to the head of the tripod by means of a loose ball-and-socket joint. The plate f has four levelling screws inserted in it; with these the instrument may be brought to a horizontal position even when the lower plate is considerably inclined.

One of the Y's is movable for a short space up or down by means of the capstan-head screw o . The spirit-level is likewise movable both vertically and laterally by means of screws at either end.

n is a clamp screw, and p a tangent-screw for slightly turning the telescope in a horizontal direction.

To adjust the Level.

First. To make the line of collimation coincide with the axis of the telescope.

Set the instrument firmly, and direct the telescope toward some distant, distinct object, such as a nail-head. Clamp fast, and with tangent-screw fix the line of collimation upon the object accurately. Revolve the telescope half way round in the Y's, *i. e.* until the bubble is above it, and if the horizontal spider-line still covers the point, it requires no adjustment. If it does not, reduce the error one-half by means of the diaphragm screws, and complete the reduction with the capstan-head screw. Revolve the telescope round to its first position, and if the horizontal line and point do not then coincide, repeat the operation until they do, in any position of the telescope. In similar wise the vertical hair may be adjusted, when the line of collimation should cover the point through an entire revolution of the telescope.

Great care should be taken in this as well as in all other adjustments of cross-hairs, that the opposite screw of the diaphragm be loosened before tightening its fellow, or injury to the instrument must result.

Second. To make the axis of the spirit-level parallel to the line of collimation.

With levelling screws bring the bubble to the middle of its tube, reverse the telescope in its Y's, and if the bubble does not then stand in the middle correct one-half the deviation with the screw at the left end of the bubble-case, and the other half with the capstan-head screw. Again reverse the telescope in its Y's, and, if necessary, repeat the operation.

Now revolve the telescope a short distance in its Y's, so as to bring the spirit-level to one side of its lowest position. If the bubble deviates from the middle, correct the error

with the lateral screws at the right end of the bubble-case, and examine the previous adjustment before lifting the instrument.

Third. To bring the line of collimation parallel to the bar.

Turn the telescope until it stands directly over two of the levelling screws, and with them bring the bubble to the middle of the tube. Then revolve the telescope horizontally until it stands over the same screws, changed end for end. If the bubble does not still stand in the middle of the tube, correct one-half the deviation with the capstan-head, and one-half with the levelling screws.

Place the telescope over the other levelling screws and proceed in a similar manner, and continue the corrections until the bubble stands without varying during an entire revolution of the instrument upon its axis.

This completes the adjustment of the level.

THE ROD.

The rod used in levelling consists of a staff and a target, which latter is so attached to the staff as to be movable along it from end to end. The rod is commonly seven feet long, but, being composed of two rectangular pieces fitted together by means of a sliding groove, it can be extended to nearly double that length. It is graduated to feet and tenths of a foot. The target is a circle of wood or iron, usually four-tenths in diameter, and divided into quadrantal sectors by a horizontal and vertical line which intersect at its centre. The sectors are painted alternately red and white, so that their dividing lines are visible at a considerable distance. On the back of the target, where it meets the graduated side of the rod, is fixed a chamfered brass edging, whereon the space of one-tenth is graven from the centre down. This is subdivided into ten spaces marking

hundredths, and these latter divided into halves, so that the height of the middle of the target above the base of the rod may be accurately read to within $\cdot 005$ of a foot.

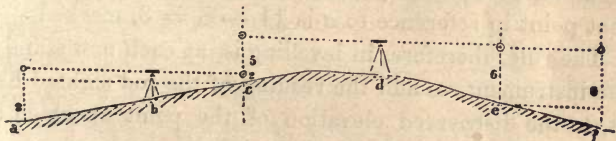
There is a similar graduated tenth on the standing part of the rod, to be used for high sights when the sliding groove comes into play.

Both target and rod are provided with clamp screws.

LEVELLING.

The operation technically called levelling is performed thus:—

Suppose a the starting point, or zero, in reference to which all the inequalities of the surface along the line of survey are measured, as at the points c, e, f . The horizontal line af is called the *datum* line. This is arbitrarily



assumed. It may be considered, for example, at any distance *above* the point a , and the irregularities of the ground measured from an imaginary level line in ether; but for convenience of figuring, and other politic reasons, it is customary in seaport towns to take high tide as datum. Inland, the summer surface of the nearest stream, or, when commencing on a ridge, the highest neighbouring knoll is assumed.

Well! suppose a to be zero, and the instrument, for instance, set and levelled at b . Stand the rod at a , and slide the target up until its cross-lines are covered by the cross-hairs in the telescope; *i. e.*, until the line of collimation coincides with the centre of the target. The leveller directs the movements of the target by raising or lowering

his hand. A circular motion of the hand signifies "make fast." The bubble should always be examined before the rod is taken down, and the latter should be read twice, or, if convenient, shown to the leveller, in order to guard against mistake. If in this case it reads 8 feet, the height of the instrument is then 8 feet above a . To find the elevation of c above a , take the rod thither and lower the target until coincidence results as before. If the rod reads 2 feet, of course c is $8 - 2 = 6$ feet above a .

If it is necessary to lift the instrument here, a small peg is driven at c before sighting to that point, to insure firm footing for the rod. Sighting back from the new position, d , the rod reads 5 feet; then $5 + 6$, the elevation of c above a , = 11, the height of the telescope at d above a . If at e the reading is 6, the elevation of that point is $11 - 6 = 5$, and if at f the reading is 8 the elevation of that point in reference to a is $11 - 8 = 3$, marked + 3.

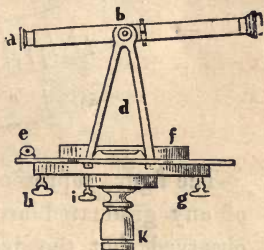
The rule, therefore, in levelling is, at each new stand of the instrument, to add the reading of the rod sighted back at, to the discovered elevation of the point at which the rod stands, for the height of the instrument; and to *subtract* from this height the reading of the rod at any points observed from the new position in order to find the elevation of those points. The above is noted in the field-book as follows:

Station.	Rod.	Height of Instrument.	Total, or Elevation.
a	8.00	8.00	00
c	2.00		+ 6.00
	5.00	11.00	
e	6.00		+ 5.00
f	8.00		+ 3.00

The advantages of this method of levelling over the old system of backsights and foresights are, that it affords readier facilities for testing the correctness of the work, and it may be carried on more rapidly. By the old plan each sight at the rod was linked with that which preceded it, and added one more to a continuous calculation in which a single error affected all the following work. Here, however, if haste is required, the calculation of the intermediate sights or "cuttings" may be omitted entirely while in the field, the reading of the rod only being set down; the "totals" may be worked from peg to peg, and the liabilities to mistake thus decreased about eighty per cent.

OF THE TRANSIT.

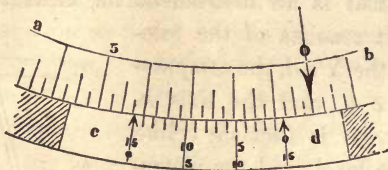
The transit is an instrument for measuring horizontal angles. It consists of the telescope *a c*, the Y's *d*, the compass-box, &c., *e g*, and the axis *k*. The telescope is furnished like that of the level, and the instrument is similarly fitted to its tripod. The telescope revolves in a vertical circle, and is attached to the Y's by means of a transverse axis whose extremities turn in smooth journals at the head of the Y's. The body of the instrument at *f* contains a magnetic needle, with its usual circular surrounding, graduated to degrees and quarter degrees. The flooring of this box has, on one side, an opening with chamfered edge upon which the vernier is engraved. This latter, together with the telescope, Y's, and all the upper part of the instrument, is made to revolve by means of the screw *h*, upon a solid plate beneath, which is likewise graduated from 0 to 180° each way. Thus angles may be measured



accurately without using the needle at all. It need be regarded merely as a check. *g* is a clamp screw for securing the plates together, and *i* a screw for fastening the needle so as to prevent its vibrations while the instrument is being carried from place to place. A plumb is suspended from the axis of the transit, by means of which its centre may be placed over a point on the ground.

THE VERNIER.

The vernier, in the transit, is a graduated index which serves to subdivide the divisions of the graduated arc on the lower plate. There are many varieties of the vernier, but familiarity with one renders easy the acquaintance with all, since the same general principle is pervading.



The figure represents a common form. Let *a b* be part of any graduated arc, and *c d* the vernier. It will be observed that the degrees on the limb are divided into spaces of 15' each. Now if the vernier be made equal in length to fourteen of those spaces, and be further divided into *fifteen equal parts*, it is evident that each of these parts will contain 14'.

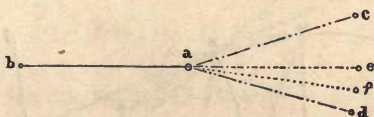
Then, if 0 of the vernier coincides with any division of the limb, the first line of the vernier to the left will be just one minute behind the first line of the limb to the left; the *second* vernier line *two* minutes behind the second limb line, and so on; so that if the vernier be moved to the left over the space of 15' on the limb, the lines from 0 to 15 of the vernier would coincide successively with lines

of the limb, and thus any angle may be read accurately to minutes.

The vernier in the figure reads $48'$ to the left. A vernier graduated decimally is much more convenient on railway locations than those with the common graduation to minutes. This is principally on account of its adaptedness to running in curves when the 100 feet chain is used. The work can be done with more ease and rapidity. One objection to it is that the tables in general use are calculated for degrees and minutes.

TO ADJUST THE TRANSIT.

Place the instrument firmly at a , level it, clamp all fast, and with tangent-screw set the cross-hairs on the point b , at any convenient distance. Reverse the telescope on its axis, and fix another point in the opposite direction,



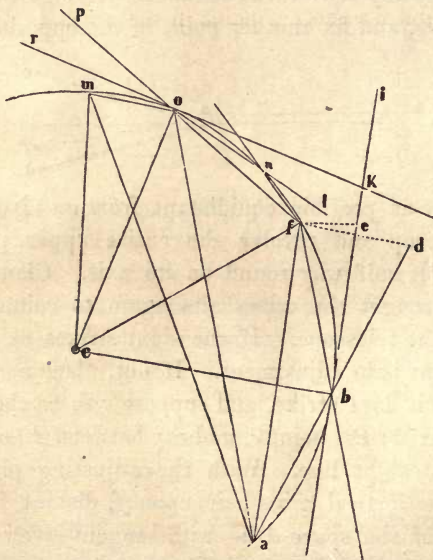
as nearly as possible equidistant from a . Now loose the lower clamp and revolve the entire upper part of the instrument half way round on its axis. Clamp fast, and having brought the cross-hairs again to coincide with b , reverse the telescope. If the sight strikes as before, the instrument is in adjustment. If not, place another point, d , where it does strike, and suppose c to be the point previously fixed: the point e , midway between d and c , is then in the straight line. With the adjusting pin carefully place the vertical cross-hair upon f , distant from d one-quarter of the space $d c$ —with tangent-screw set it on e , and reverse the telescope. If the points have been correctly placed, and the hair properly moved, the sight will strike b , and the adjustment is complete.

After finishing this adjustment, the telescope may still not revolve truly in the meridian. This inaccuracy there is no method of removing in the field. It should be sent to an instrument-maker for repairs.

ARTICLE II.

PRELIMINARY PROPOSITIONS.

1. *In any circle the angle ocf at the centre, subtended by the chord of , is double the angle oaf , at any part of the circumference on the same side of the chord.*



2 *The angle fbe , formed by any chord fb , with a tangent at either extremity, is called a *tangential angle*.*

and is equal to half the angle fcb at the centre, or is equal to the angle fab at the circumference.

3. The exterior angle $d b f$, formed at the circumference by the two equal chords $a b, b f$, is called a *deflexion* angle, and is equal to the central angle $b c f$, or double the tangential angle $e b f$. $d f$ is called the *deflexion distance*, and $e f$ the *tangential distance*.

4. *The exterior angle $p o m$ of two unequal chords, is equal to the sum of their tangential angles, or half the sum of their central angles.*

5. The exterior angle $ik o$, formed by tangents, is equal to the central angle $b c o$, subtended by the chord which connects their points of contact with the curve.

ARTICLE III.

TO AVOID AN OBSTACLE IN THE LINE OF TANGENT.

A GLANCE at the figure will show, that having deflected to c , and placed the instrument at that point, the angle $h c d$ must be made equal to twice $d b c$, and the distance



cd equal to the distance bc . Still another deflection at d , equal to the original angle turned, is necessary in order to sight again along the tangent.

Should the obstruction be continuous a parallel line may be run, as from *c* to *f*, by deflecting at *c* an angle

equal to that at b , and at f , repeating the deflection in order to strike tangent.

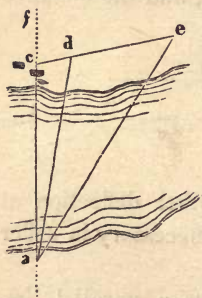
If the angle $d b c$ exceeds 4° , and the distance $b c$ is greater than 200 feet,—or even with an angle of $2\frac{1}{2}^\circ$, should the distance be greater than 300 feet,— $b c$ will differ sensibly in length from $b k$, and a calculation of the latter becomes necessary. To effect this, multiply the natural cosine of the angle $k b c$ by $b c$. This result *doubled* will give $b k d$, the length proper along tangent.

Thus:—Suppose $k b c$, the angle deflected, to have been 5° , and the distance $b c$ 340 feet. Then $\cdot 9962$, the natural cosine of 5° , multiplied by 340, gives 338.7 for the distance $b k$. Double this makes $b k d = 677.4$, and shows a difference of 2.6 feet between $b d$ and $b c d$.

ARTICLE IV.

SHOULD THE OBSTRUCTION LIE ON THE OPPOSITE BANK OF A STREAM,

AND it is desirable on any account not to run the line from d , corresponding to $a d$, set the instrument at a , in tangent, and deflect clear of the obstacle to d . Point at d , deflect to e , and point also there—marking the angles $c a d$, $d a e$. Chain the base $d e$, and placing the transit at e , measure the angle $d e a$. Data are thus obtained sufficient for the calculation of the line $d a$. The object now is to find the point c and the angle $d c a$. The angle $a d e$ subtracted from 180° will supply the



angle cda , so that in the smaller triangle we have obtained two angles and their included side. The distance cd , and angle dca readily follow. The transit standing at e , c is placed, of course, in the prolongation of the base de , and the distance cd is carefully set off with the rod. Moving the instrument to c , and turning the angle $ecf = 180^\circ - dca$, we are again in tangent.

Example.—Let $cad = 6^\circ$, $dac = 35^\circ$, $dea = 42^\circ$, and the base $de = 200$ feet. Then in the triangle dea we have

$$\text{Nat. sine } dae = (.5736) : \text{nat. sine } dea = (.6691) :: de = (200) : da,$$

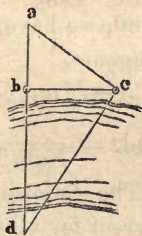
$$\text{Wherefore, } da = \frac{.6691 \times 200}{.5736} = 233.3 \text{ feet.}$$

Again, the angle $cda = 77^\circ$. The angle dac being $= 6^\circ$, acd is consequently $= 97^\circ$, and in the small triangle we have, $\text{Nat. sin. } acd = (.9925) : \text{nat. sin. } cad = (.1045) :: da = (233.3) : cd$.

$$\text{Therefore } cd = \frac{.1045 \times 233.3}{.9925} = 24.564 \text{ feet, and } dcf$$

$$180^\circ - 97^\circ = 83^\circ.$$

NOTE.—A common and convenient plan for triangulating a creek is as per figure. Set the instrument at b , fix a point d on the opposite shore, and making dbc a right angle, place c at any convenient distance. Now move to c , sight to d , and making dca a right angle also, fix a , in the same line with b and d . a , c , and d are points in the circumference of a circle whose diameter is ad , $ab : bc :: bc : bd$, and therefore $bd = \frac{bc^2}{ab}$.



ARTICLE V.

HAVING GIVEN THE ANGLE edb , FORMED BY THE INTERSECTION OF TWO STRAIGHT LINES, IT IS REQUIRED TO FIND THE POINT a OR b , AT WHICH TO COMMENCE A CURVE OF GIVEN RADIUS.

Draw the bisecting line dc . Then the angle $dca =$

half the angle acb or its equal edb ; and in the triangle dca , the angle dca being a right angle, we have

Rad. of 1 : Nat. Tang. dca : Rad. ca : ad . Therefore $ad = \text{Nat. Tang. } dca \times \text{Rad. } ca$.

Example 1.—Let $edb = 48^\circ$ and $ac = 1460$ feet. Here half the angle edb or $acb = 24^\circ$, the

Nat. Tang. of which is .4452; and multiplying by Rad. 1460, we have 650 feet for the length of ad or db , the tangents.

2.—If ad be given and radius required,—

$$\text{Rad.} = \frac{ad}{\text{Nat. Tang. } acd} = \frac{650}{.4452} = 1460.$$

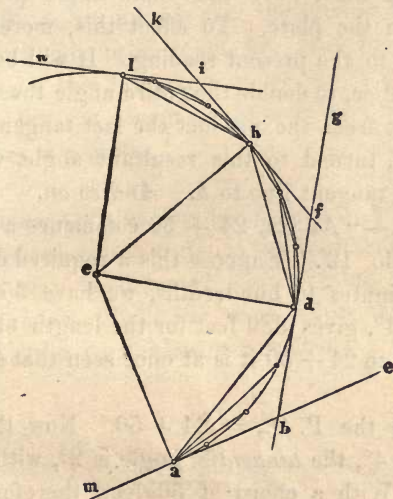
The following rules are approximate, and sufficiently correct for all purposes of location.

To find the degree of curvature of ab divide 5730 by the radius in feet; and to find the length of the curve in feet divide the angle acb (after reducing minutes to hundredths) by the degree of curvature—the chord in each case being 100 feet in length.

ARTICLE VI.

TO TRACE A CURVE WITH TRANSIT AND CHAIN.

THE degree of curvature and the angle to be turned are known. If the latter is expressed in degrees and minutes, reduce the minutes to hundredths, since the 100 feet chain is used, and divide the whole angle by the degree of curvature. The quotient will be the length of the curve in feet, and the P. T. is at once ascertained.



Let ma be the tangent, and a the P. C. Place the transit at a , index reading 0, and direct the sight along the tangent mae . The first deflection will be half the central angle subtended by the chord used, and all the stakes put in from a will be fixed by similar tangential deflections. (*Prelim. Prop. 1.*)

When the point d is reached, the angle dab , shown on the index, will be half the angle dbe , or its equal acd , at the centre. Move the instrument to d , sight back to a , and turn to *double the index angle*. The telescope is now directed along the tangent bdg , and the angle $dbe = acd = dab + adb$, reads on the index. Note this angle in the column of tangents opposite station d . Continue the curve from this new position, precisely as was done at a , and set the point h . Move to h , see that the vernier has not been disturbed, and sight back to d . The index now shows the angle $(dbe + hdg)$, and the object is to turn the angle $d hf$, i. e. *repeat* the angle $f dh$, as was done before at d , and, at the same time, have the whole angle $(dbe + hfg)$ indicated on the plate. To effect this, merely add this angle fhd to the present reading. It will be found simpler, in practice, to double the entire angle thus far turned, and subtract from the product the last tangent, viz. dbe . The vernier, turned to this resultant angle, will put the telescope in tangent line to h . *And so on.*

Example.—"At sta. $24 + 50$ commence a 4° curve to the left for $35^\circ 12'$." Suppose this a required duty. First, reducing minutes to hundredths, we have $35^\circ \cdot 20$, which, divided by 4° , gives 880 feet for the length of the curve. Adding 880 to $24 + 50$ it is at once seen that sta. $33 + 30$ is the P. T

Let a be the P. C., $= 24 + 50$. Now the *deflexion angle* being 4° , the *tangential angle* is 2° , with a chord of 100 feet. With a chord of 50 feet, therefore, the tangential angle is 1° , and this deflexion from tangent mae fixes station 25. A deflexion from this latter point of 2° , the chord being 100 feet, fixes station 26. *And so on.*

When you have fixed the point d , $=$ sta. 28, the index reads 7° . Move up to station 28, sight back to the P. C., and turn the index to 14° . This throws you on tangent

Proceed as before, with the 2° deflexions, to sta. 31, = h . Move up, and sight back to sta. 28. The index now reads 20° . Multiplying by 2, and subtracting the last tangent, we have the reading of the tangent at $h = 26^\circ$: we have turned 26° of the curve. Continue as before. After putting in sta. 33, to find the deflexion which shall fix the P. T., $33 + 30$, say, as 100 feet : 30 feet :: 2° : the required deflexion, = $36'$. We may here remark the great convenience of an instrument graduated to *hundredths* of a degree instead of *sixtieths*. In the present example it would be seen immediately that the tangential angle for 100 feet being 2° , for 1 foot it would be 2 *hundredths* of a degree, and for 30 feet it would be 60 hundredths.

Well! when the P. T., = $33 + 30$, is fixed, the index reads $30^\circ 36'$. Move up, see that the vernier has not been disturbed, and sight back to sta. 31. Now twice the index reading, minus the last tangent, = $61^\circ 12' - 26^\circ$, = $35^\circ 12'$, the present tangent, which is the final tangent, which finishes the curve.

The advantage of this manner of running a curve is that the instrument shows at a glance the work done, and therefore errors may be detected with greater facility. By comparing at the P. T. the total index angle with the distance run, the work is tested at once.

The above is recorded in the field book as follows:—

Station.	Distance.	Deflex'n.	Index.	Tangent.	Course.	Mag. Course.	Remarks.
23°	100ft.				N. 20° 00 W.	N. 20° 05 W.	At sta. 24 + 50 commence a 4° curve to the L. for 35° 12'.
24	50	1° 00	1° 00				
P. C. + 50°	50	2° 00	3° 00				
25	100	2° 00	5° 00				
26	100	2° 00	7° 00				
27	100	2° 00	16° 00	14° 00		N. 34° 07' W.	
28°	100	2° 00	18° 00				
29	100	2° 00	20° 00				
30	100	2° 00	28° 00	26° 00			
31°	100	2° 00	30° 00				
32	100	2° 00	30° 36'				
33	30	0° 36'		35° 12'	N. 55° 12 W.	N. 55° 18' W.	
P. T. + 30°	70						
34	100						

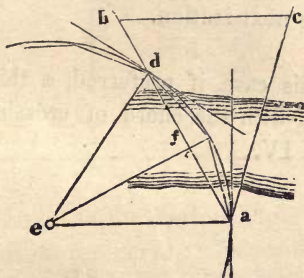
In running compound and reversed curves the operation is quite as simple as the foregoing. A point is fixed at the P. C. C., or P. R. C., and turning into tangent at that point, the second curve is traced from this *tangent*, without regard to what precedes. In reverse curving, it is a good plan to adjust the index in such manner at the P. R. C., that when we turn into tangent it will read 0.

This saves troublesome work, and it is advisable moreover to show in the field-book the contained angle of *each curve*, as well as the test of the two tangents with the magnetic course.

ARTICLE VII.

TO TRIANGULATE ON A CURVE.

SET the transit at a , and, as usual, sight back, and turn into tangent. Estimate the distance to the farther bank—do it liberally—and make a deflexion around the curve, corresponding to your estimated distance. Fix a point b in this line. Measure any convenient angle, $b a c$, and set



the point c . Move to b , measure the base $b c$, the angle $a b c$, and, before lifting the instrument calculate the line $b a$. If the angle turned from tangent to d exceeds 4° , and the distance is greater than 200 feet, the chord $a d$ must also be calculated, as per example, and the difference between this and $b a$ will be the distance $b d$ to the point d , in the curve, which can be fixed from b .

Should b fall between d and a the operation is analogous.

Example.—Let a be a point in a 6° curve. Having set the transit, and turned into tangent, the distance to the farther verge is estimated 400 feet. The tangential angle for 100 feet is 3° , and to fix d , 400 feet distant, is consequently 12° . Deflect this angle, fix a point in line, and complete the triangulation, as previously illustrated in Art. IV., p. 22. Suppose ab found equal to 472 feet. Now the tangential angle to $d =$ half the central angle, $= fea, = 12^\circ$; and to find the length of the chord ad , we have, in the triangle efa ,

Rad. : Sin. $ae f :: ea : af$, that is

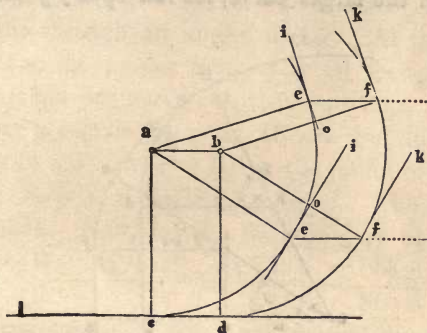
Rad. of 1 : Nat. Sin. $12^\circ :: 955.4$, the Rad. of the 6° curve : half the chord required. Wherefore $ad =$ twice the Nat. Sin. $12^\circ \times 955.4 = .2079 \times 2 \times 955.4 = 397.25$ feet. Subtracting this from 472, we have the distance, 74.75 feet, back to the point in the curve. Move the instrument to d , set the index at 12° , sight back to a , and turning to 24° , the telescope is in tangent. A deflexion of 3° will fix the next station.

NOTE.—In this case, if preferred, a third proportional might be formed with the chord of crossing, as shown in the note to Art. IV.

ARTICLE VIII.

TO CHANGE THE ORIGIN OF ANY CURVE, SO THAT IT SHALL TERMINATE IN A TANGENT PARALLEL TO A GIVEN TANGENT.

LET df be the located curve, terminating in a tangent fk , and the nature of the ground requires that it should terminate in the tangent ei , parallel to fk . At f , the telescope being directed along the tangent fk , turn to the

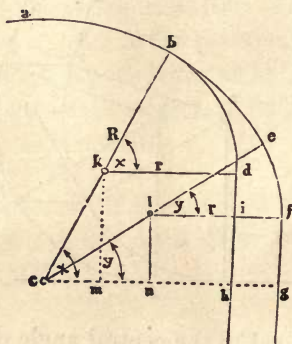


right an angle equal to the central angle dbf , previously turned to the left on the curve. This will direct the telescope along ef , parallel to dl . Measure ef , and go back on the tangent, dl , a distance, cd , equal to it. The curve, retraced from c and consuming the same angle, will terminate tangentially in ei . An example in this case is not necessary.

ARTICLE IX.

TO CHANGE A P. C. C. SO THAT THE SECOND CURVE SHALL TERMINATE IN A TANGENT PARALLEL TO A GIVEN TANGENT.

LET $a b d$ be the compound curve, located and terminating in the tangent $d h$. Continue the larger curve to e , and from e , with radius $e l = k b$, describe the curve $e f$, terminating tangentially in $f g$, parallel to $d h$. From e , the centre of the larger curve, let fall upon $f g$ the perpen-



dicular $c g$, and fill up the figure as above. Call the radii respectively R and r , the angle $b k d$, or its equal, $k e m$, x , and the angle $e l f$, or its equal, $l c n$, y . Let the distance $i f$, or $h g$, be named D . Now the line $c g$ is made up of the lines $c m + m h + h g$, i. e., $c g = \cosin. x (R - r) + r + D$. $c g$ is also made up of the lines $c n + n g$, i. e., $c g = \cosin. y (R - r) + r$. Therefore $\cosin. x (R - r) + r + D = \cosin. y (R - r) + r$, and reducing,

$\text{cosin. } y = \frac{\text{cosin. } x (R - r) + D}{(R - r)}$; so that the distance if ,

or hg , measured rectangulary between the two tangents, being added to the nat. cosin. x , will give the nat. cosin. of the angle elf , to be turned on the smaller curve. The angle y , subtracted from the angle x , gives of course the angle bce , to be advanced on the larger curve; or, dividing this angle by the degree of curvature of ab , we find the distance from b to e the P. C. C. proper.

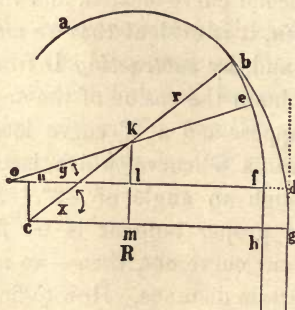
If ef be the second curve located, and the tangent to be touched lies *within*, it is evident that we must *retreat* upon the large curve, and, by *subtracting* D from the cosine of the angle y , we obtain the cosine of the angle x .

Example.—Suppose ab a 3° curve located, and compounding, at b , into a 6° curve, which latter is continued to the right through an angle of 42° . At the P. T. we discover that the proper tangent is 64 feet to the left. We must throw our curve *out*, then—we must *advance* on the 3° curve a certain distance. How to find this distance: The radius of a 3° curve = 1910; the radius of a 6° curve = 955.4; $R - r$, therefore, = 954.6. The nat. cosin. $42^\circ = .7431$. Now, by the formula just obtained, we have
$$\frac{\text{cos. } x (R - r) + D}{(R - r)} = \frac{(.7431 \times 954.6) + 64}{954.6} = .8101 = \text{nat. cosin. } 35^\circ 53'.$$
 Subtracting this from 42° , we have $6^\circ 07'$, the angle to be advanced on the 3° curve; or, reducing minutes to hundredths, and dividing by 3° , we find 204 feet, the distance from b to the correct P. C. C.

ARTICLE X.

SHOULD THE SECOND CURVE BE ONE OF LONGER RADIUS THAN THE FIRST,

OUR illustration takes simpler form, and the application of D varies *vicê versa*.



See figure, analogous to that of the previous problem. Here of, cg are equal and parallel radii; fh a perpendicular connecting them. Draw its fellow, cn . Then, $nf = ch$, and, consequently, $hg = on$. Again, letting km fall, perpendicular to cg , we have $cm = nl$, and $ol = cm + on$; i. e., $\cosin. y (R - r) = \cosin. x (R - r) + D$.

We observe that, with a curve of this nature, in order to throw the line *farther out*, it is necessary to *go back*, toward b ; or, having located to g , if the object tangent lie *within*, we must *advance* toward e .

Example.—Suppose ab a 5° curve, b the P. C. C., and bg a 2° curve. Setting the instrument at g , the P. T., and turning into tangent, we find that we are a distance $hg, = 53$ feet, too far to the *left*. The first question is, what angle have we turned on the second curve. Let it

be 28° . Now we know, that, in order to strike farther to the *right*, we must advance on the 5° curve. Consequently, *D* must be *added* to the cosine of 28° , to give us the cosine of the proper angle for the 2° curve; and the difference between 28° and this newly found angle will be the angle we are to advance on the 5° curve. Thus:—the rad. of a 5° curve = 1146 feet, that of a 2° curve = 2865 feet and their difference = 1719 feet. The nat. cos. of 28° = .8829. Then $\frac{(.8829 \times 1719) + 53}{1719} = .9137$, = nat. cos. $23^\circ 58'$. This, subtracted from 28° , leaves $4^\circ 02'$, = 80 feet, from *b* to the correct P. C. C.

Synopsis of the preceding formulæ.

Call *D* the distance between tangents as before, *a* the angle of the second curve located, and *b* the angle of the same curve to be substituted for it.

FIRST, when the second curve has the *smaller* radius—

Tangent falling *within* the point, cosine *b* =
$$\frac{\cos. a (R - r) + D}{(R - r)}.$$

Tangent falling *without* the point, cosine *b* =
$$\frac{\cos. a (R - r) - D}{(R - r)}.$$

SECOND, when the second curve has the *larger* radius—

Tangent falling *within* the point, cosine *b* =
$$\frac{\cos. a (R - r) - D}{(R - r)}.$$

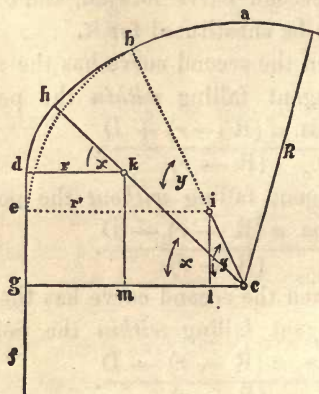
Tangent falling *without* the point, cosine *b* =
$$\frac{\cos. a (R - r) + D}{(R - r)}.$$

Very little attention will familiarize these formulæ, and render the field practice easy.

ARTICLE XI.

HAVING LOCATED THE COMPOUND CURVE abd , TERMINATING IN THE TANGENT df , IT IS REQUIRED TO FIND THE P. C. C. b , AT WHICH TO COMMENCE ANOTHER CURVE OF GIVEN RADIUS, WHICH SHALL ALSO TERMINATE TANGENTIALLY IN df .

PLOT the curves as per figure. From c let fall cg , perpendicular to the tangent, df . From k and i , the lesser centres, drop km , il , perpendicular to cg . Call the great radius R , the smaller radius r , and the *intended* radius of



the second curve r' . Likewise name hkd , the angle of the small curve located, x , and bie the angle to be found for the *proposed* curve, y . Now, the tangent df , and the curve ab , lying unstirred, the line cg is an unvarying distance, and it is made up of the lines $cm + mg$, i. e., $cg = (R - r) \cosin. x + r$. It also consists of the lines cl

+ lg , i. e., $cg = (R - r') \cosin. y + r'$, and, reducing,
 nat. $\cosin. y = \frac{(R - r) \cosin. x + r - r'}{(R - r')}$. This, there-
 fore, is the formula by means of which we can ascertain
 the point b , as follows:—

Example.—Imagine a 2° curve, ah , compounding into
 a 6° curve, hd , which terminates at d , in the tangent df .
 The tangent lies well; the curve ah likewise; but it is
 desired to throw the line to the left, on better ground,
 between d and h , by means of an intercalary 4° curve.
 We wish, then, to know the distance, hb , back to the new
 P. C. C.

The radius of a 2° curve = 2865 feet, of a 6° curve =
 955.4 feet, and their difference $(R - r) = 1909.6$. The
 radius of a 4° curve = 1433, and the difference $(R - r')$
 is, therefore, 1432 feet. Let hkd , the angle turned on
 the 6° curve, be 41° , the nat. cos. of which = .7547.

Then, $\frac{(.7547 \times 1909.6) + 955.4 - 1433}{1432} = .6728, =$

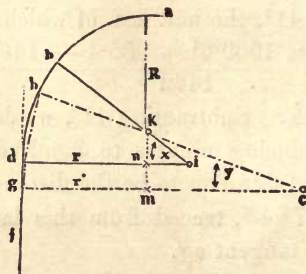
nat. $\cosin. 47^\circ 43'$. Subtracting 41° , we have $6^\circ 43'$, the
 angle hcb . Reducing minutes to hundredths, and divid-
 ing by 2° , we find 336 feet to be the distance from h to b .
 A 4° curve of $47^\circ 43'$, traced from this latter point, will
 terminate in the tangent ef .

ARTICLE XII.

IF THE LATTER CURVES HAVE LARGER RADII THAN THE FIRST,

THE solution retains its shape and simplicity.

Draw the figure as above, and, for the sake of uniformity, name the radii as before. The curve ab , and tangent df , being constant, the distance mg , or dn , is here constant. Call it A . Now A , in the first place, is equal to $di - ni$, i. e., $= r - (r - R) \cosin. x$; and, in the second place,



it is equal to $gc - mc$, $= r' - (r' - R) \cosin. y$; wherefore $r - (r - R) \cosin. x = r' - (r' - R) \cosin. y$, and consequently $\cosin. y = \frac{(r - R) \cosin. x + r' - r}{(r' - R)}$.

Example.—Suppose ab a 7° curve, compounding, at b , into a 5° curve, bd , which latter subtends an angle of 38° , and terminates in the tangent df . We wish to substitute a terminal 2° curve, hg , and to know the position, h , of the new P. C. C.

The radius of a 7° curve $= 819$ feet $= R$. r and r' ,

the radii respectively of 5° and 2° curves, are equal to 1146, and 2865 feet. $r - R$, therefore, = 327, and $r' - R = 2046$ feet. The nat. cosin. of $38^\circ = .788$.

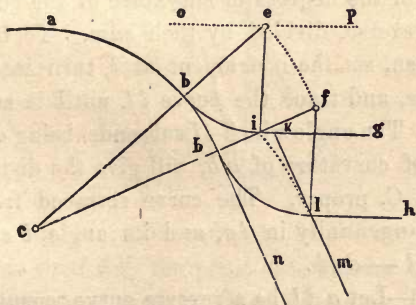
Then, by the formula, $\frac{(.788 \times 327) + 2865 - 1146}{2046} =$

·9661, = the nat. cosin. of $14^{\circ} 57'$, the angle to be turned on the 2° curve. Subtracting this from 38° , we have $23^{\circ} 03'$, the angle to be continued on the 7° curve. Reducing minutes to hundredths, and dividing by the degree of curvature, 7° , we find 329 feet, the distance from b to the new P. C. C. h .

ARTICLE XIII.

TO CHANGE A P. R. C., SO THAT THE SECOND CURVE SHALL
TERMINATE IN A TANGENT PARALLEL TO A GIVEN TAN-
GENT.

LET adl be the reverse curve, located and terminating



in the tangent lh . Call the radius cb , R , and the radius be , r . Supposc ig the given tangent. At a distance

from it equal to ie , the radius of the second curve, draw the parallel line, op . With c as a centre, and radius cf , $= R + r$, describe the integral curve, fe , cutting op in e . e , then, is the centre of the curve adjusted.

Application.

Place the transit at the P. T., l , and turn into a tangent, lm , parallel to dn , the common tangent of the two curves at d . Unless some wide mistake has been made, the distance lk , measured along this line to ig , the tangent proper, will be about equal to the distance ef , and we shall have the proportion, $cf : fe :: cd : db$, i. e., $R + r : ef :: R : db$, which gives $\frac{fe \times R}{R + r}$, as a simple formula for finding the distance back from d to b , the correct P. R. C. This rule, though sufficiently true for most cases, is not mathematically justifiable. It will be seen that ef , or its equal il , the distance we wish to measure, is a *curving* distance, part of the circumference of a circle concentric with ab . Its radius is $(R + r)$, therefore its degree of curvature $= \frac{5730}{(R + r)}$, or, more simply, equals the *product* of the degrees of curvature of the curves composing the reverse, divided by their *sum*. To be strictly accurate, then, set the instrument at l , turn into tangent lm as before, and trace the curve il , until it strikes the tangent ig . The angle which il subtends, being divided by the degree of curvature of ab , will give the distance, db , to the P. R. C. proper. The curve retraced from b , will terminate tangentially in ig , and its angle, bei , will be equal to $dfl - dcb$.

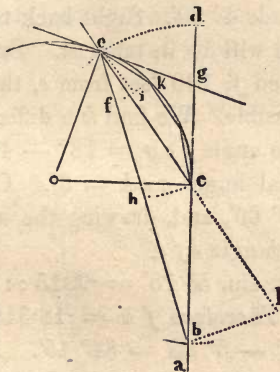
Example.—Let adl be a reverse curve, composed of a 3° curve, ad , and a 6° curve, dl . Let the angle dfl be equal to 52° , and suppose the distance lf to have been

found 34 feet. Being part of a 2° curve, it therefore subtends a central angle of $41'$. This corresponds to a distance of 23 feet, to be gone back on the 3° curve, and $52^\circ 00' - 41' = 51^\circ 19'$, the angle to be turned from h on the 6° curve, in order to strike the tangent ig .

ARTICLE XIV.

HOW TO PROCEED WHEN THE P. C. IS INACCESSIBLE.

IN the figure, drawn to illustrate this case, let c be the point of curvature, ca the tangent, and cke the curve. Now the angle dce , included between the tangent and



any chord, as ce , fixing the point e , is known. Make cb along tangent, equal to ce , and connect be . If a circle were now described from c as a centre, with radius ce or cb , d , e , and b , would be points in its circumference, and

the angle $d b e$ at once proven equal to half the angle $d c e$. With proof precisely similar, $d c e =$ half of $d g e$, and, consequently, $d b e$ is equal to one-fourth of the central angle subtended by the chord $c e$.

Example.—Suppose c to be the inaccessible point of curvature of a 6° curve, $c k e$. It is concluded to run to the third station, e . First we must calculate the length of the chord $c e$. The angle $d c e = 9^\circ$, and from Art. VII. we have

Rad. of 1 : 955.4 :: nat. sin. $9^\circ = .1564 : \frac{e c}{2}$, whereby

$e c$ is shown equal to 298.8. Place the transit then at b , 298.8 feet distant from the P. C., and deflect to the left an angle of $4^\circ 30'$, equal to half the angle $d c e$. This is in line to e , and $b e$ must likewise be calculated as follows:

In the triangle $b c h$ we have

Rad. of 1 : nat. cosin. $4^\circ 30' = .9969 :: b c = 298.8 : b h = \frac{b e}{2}$, whereby $b e$ is shown equal to 595.7 feet. Arriving

at e , the index reads $4^\circ 30'$. Sight back to b , turn to 18° , and the telescope will be in tangent. Suppose, however, that having reached f , 100 feet from e , this latter point is also found inaccessible. We find k a different point in the curve, thus:—The angle $f e g = 18^\circ - 4^\circ 30' = 13^\circ 30'$, and the tangential angle $g e k = 3^\circ$. Consequently the angle $f e k = 10^\circ 30'$, and, drawing the bisecting line $e i$, we have, in the triangle $e f i$,

Rad. of 1 : nat. sin. $5^\circ 15' = .0915 :: e f = 100 : f i = 9.159$ feet. Therefore $f k = 18.318$ feet, and the angle $e f k = 90^\circ - 5^\circ 15' = 84^\circ 45'$. At f deflect this angle to the right, and measure the distance $f k$ carefully with the rod. At k , sighting back to f , and turning the equal angle $f k e$, the telescope will be directed to e , and the curve may be continued.

If it is inconvenient to run the line $b e$, the point e may

be reached thus:—Fix the P. C. Find the tangential distance $d e$, corresponding to the angle $d c e$. Carefully with the rod lay off $b l$, equal to it, at right angles to $b e$. Set the transit at l , and, in line with c , put in e .

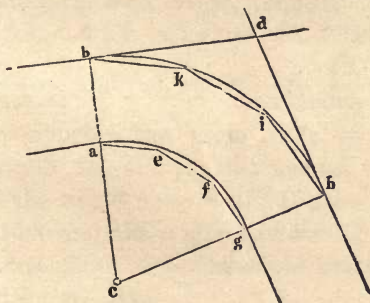
The distance $b l$ should not exceed 10 or 12 feet.

NOTE.—The foregoing illustrations will apply when the P. T. is likewise inaccessible.

ARTICLE XV.

TO AVOID OBSTACLES IN THE LINE OF CURVE.

LET $b k h$ be the curve. We can either follow the tangents $h d$, $d b$, or trace a parallel curve, $g a$, *within* the first; which tracing is effected thus:—Set the instrument



at h , the P. C., and offset any distance $h g$, at right angles to the tangent $h d$. It will be observed that as the distance $h g$ increases, the distance $g a$ decreases, whilst the angle subtended by $g a$ remains equal to that subtended

by hb ; i. e., our *deflexions* on the offset curve stand unchanged, but the corresponding *chords*, gf , fe , &c., are *less* than their equivalents, hi , ik , &c., along hb . To find their length, hi , ik , &c., being equal to 100 feet, we have the proportion, $ch : cg :: hi : x$; i. e., $R : \text{rad.} - hg :: 100 \text{ feet} : x$, where x symbols the unknown chord. Now set the transit at g , turn into tangent parallel to hd , and with the shortened chord, fix fea . Rectangularly to the tangents at these points, and distant hg , will be i , k , b of the curve proper.

Example.—Let bh be a 4° curve, and the offset distance 85 feet. The radius then is 1433, and

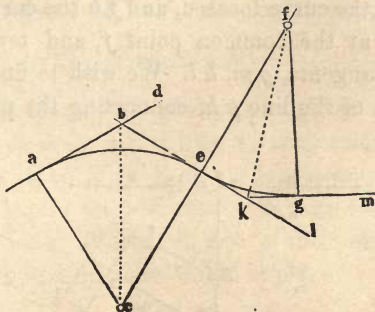
1433 : 1348 :: 100 : 94, the short chord.

To follow the tangents, suppose the angle $bch = 42^\circ$. Then by Art. V. we find the tangent $hd = 550$ feet. which distance we duly measure, and, at d , deflecting 42° , lay off an equal distance to b , the point of tangency.

ARTICLE XVI.

HAVING GIVEN THE ANGLES dbk , $mk l$, AND THE DISTANCE $b k$, IT IS REQUIRED TO FIND THE RADII $c e$, $e f$ OF THE EASIEST REVERSE CURVE WHICH SHALL UNITE $a d$, $k m$.

THE angle $d b e$ is equal to the angle $a c e$, half of which is $b c e$. So likewise $e f k$ is equal to half of $l k m$.



Then, $[\text{nat. tang. } bce + \text{nat. tang. } efk] : \text{nat. tang. } bce :: bk : be$, and $bk - be = ek$. Wherefore $\text{rad. } ce = \frac{be}{\text{nat. tang. } bce}$ and $\text{rad. } ef = \frac{ek}{\text{nat. tang. } kfe}$.

Example.—Suppose the angle $d b e = 54^{\circ} 30'$, the angle $l k g = 33^{\circ} 20'$, and the distance $b k = 832$ feet.

Therefore the angle $bce = 27^\circ 15'$, the nat. tang. of which is $\cdot 5150$, and the angle $efk = 16^\circ 40'$, the nat. tang. of which is $\cdot 2994$. The sum of the tangents $= \cdot 8144$. Then, to find be , we have

As $\cdot 8144 : \cdot 5150 :: 832 : 526$, and subtracting this from $b k$, we have $e k = 306$ feet.

Again, the radius $ce = \frac{526}{.515}$, and the radius $ef = \frac{306}{.2994}$,
 $= 1022$ feet.

the tangent to a curve at any point g , and the line $g h$ connecting g with an equivalent point h in any other curve $f h$ commencing at the same P. C., f , and turning in the same direction, is invariably equal to half the common central angle, $f d g$ or $f c h$.

Example.—Let $f g$ be a 7° curve, subtending a central angle, $f d g$, of $44^\circ 26'$. Having arrived at g , the P. T., and turned into tangent, $g m$, it is desired to fix the P. T., h , of a 4° curve which shall likewise subtend an angle of $44^\circ 26'$. Here the radii are, respectively, 819 and 1433 feet, and $R - r = 614$. The nat. sine of $44^\circ 26' = .700$, and the nat. cosine of half this angle, viz.: $22^\circ 13' = .9258$. Then, by the formula, $g h = \frac{614 \times .7}{.9258} = 464.2$.

Deflecting, therefore, to the left, an angle of $22^\circ 13'$, and laying off the distance 464.2 feet, we arrive at the point h . Move to h , sight back to g , and a deflexion of $22^\circ 13'$ to the right will direct the telescope along the tangent $h ?$.

If h were the P. T. located, and g the point required, the same angle and distance would apply.

ARTICLE XVIII.

HAVING THE CURVE nfg LOCATED, AND TERMINATING IN THE TANGENT gm , IT IS REQUIRED TO FIND THE POINT f , WHEREAT TO COMPOUND WITH ANOTHER CURVE OF GIVEN RADIUS, WHICH SHALL TERMINATE IN il , PARALLEL TO gm .

[See previous figure.]

NAME the radii and angle as before. Measure the distance gi , between the tangents, and call it D . Then ch is equal to $ce + ek + gi$ or kh ; i. e., $R = (R - r)$ $\cosin. x + r + D$, or, transposing, $\cosin. x = \frac{R - (r - D)}{(R - r)}$.

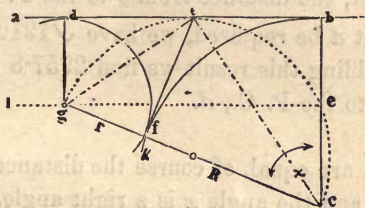
Thus discovering the angle fdg , divide it by the curvature nfg , and we have the distance, gf , to the P. C. C. f . The second curve, traced from this point, will terminate tangentially in hl .

Example.—Let the curvatures equal those of the last problem, and suppose the distance gi to be 175.6 feet. Then, by the formula, $\cosin. x = \frac{1433 - 994.6}{614} = .7143 = \cosin. 44^\circ 26'$. Reducing minutes to hundredths, and dividing by 7° , we have 635 feet, the distance back to the P. C. C.

ARTICLE XIX.

HAVING GIVEN A TANGENT ab , AND A CURVE $b k$, LOCATED,
IT IS REQUIRED TO FIND THE POINT d , OR f , AT WHICH
TO COMMENCE A CURVE OF GIVEN RADIUS, WHICH SHALL
BE TANGENT TO BOTH.

DRAW the radius bc , and call it R . Name the radius of the other curve r . Make be equal to r , and, through e , draw the line el , parallel to the tangent ab . From c as a centre, with $cg, = (R + r)$, as radius, sweep the arc of a circle; which arc will intersect el at g , and, from the equidistances, prove g the centre of the other curve touching ab, bk , tangentially, at the points d and f .



Now, to find the point f for purposes of location, we must know the angle $b c f$. Call it x . In the triangle $c g e$, we have $c g : c e :: \text{radius} : \cosin. g c e$, or $b c f$; i. e., $(R + r) : (R - r) :: 1 : \text{nat. cosin } x$, wherefore nat. cosin.

$x = \frac{(R - r)}{(R + r)}$. So that, having divided the *difference* of the radii by their *sum*, we shall find opposite to the quotient, in the table of nat. cosines, the angle *b c f* required. This angle, divided by the degree of curvature of *b k*, will

give the distance from b to the P. R. C., f ; and $180^\circ - x$ will equal the angle $f g d$, to be turned on the other curve.

Another plan, which may be preferred, for finding the point d , is as follows:

Make $c g$ the diameter of a semicircle, $c t g$. This semicircle is tangent to $b d$ at t , and $t f$, perpendicular to $c g$, is a common tangent to the curves $b k$, $d f$. We have then, $c f \times f g = t f^2$, i. e., $R \times r = \text{tang.}^2 \frac{x}{2}$. Multiplying the radii together, and extracting the square root of the product, we find the distance $t f$, or its equal $t b$, which, *doubled*, is the distance $b d$, from b to the point of curvature, d .

Example.—Suppose $k b$ a 3° curve, tangent to the line $a b$. We wish to know the point f , at which to begin a 5° curve, which shall be tangent to both. Here $R = 1910$, and $r = 1146$, wherefore $(R + r) = 3056$, $(R - r) = 764$, and $\frac{(R - r)}{(R + r)} = \frac{.764}{3056} = .25 = \text{nat. cosin. } 75^\circ 31'$. Reducing minutes to hundredths, and dividing by 3° , we have 2517 feet, the distance from b to the P. R. C., f .

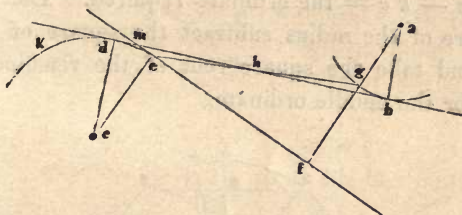
If the point d be required, we have $\sqrt{1910 \times 1146} = 1478.9$. Doubling this result we find 2957.8 feet, the distance from b to the P. C., d .

If the radii are equal, of course the distance $b d$ is equal to their *sum*, and the angle x is a right angle.

ARTICLE XX.

TO RUN A TANGENT TO TWO CURVES.

LET $g b$, $e k$, be the two curves. First plot them carefully to a large scale, and, finding from this plot an approximate P. T., say e , run the tangent ef . Now the chord in the curve $g b$, to which ef is parallel, is known, and consequently the shortest distance, fg , between the tangent and the curve may be measured. Then $ef : fg :: \text{rad.} : \text{tang. } feg$, and $\text{nat. tang. } feg = \frac{fg}{ef}$. Practically, this angle feg will be found equal to gab or dce , so that, dividing it by the degree of curvature of ke , we shall have the distance, ed , to the proper P. T.



Strictly speaking, the angle gef is too great by the small angle bhg . There are two modes of calculating this latter, but they are both complex, and in any but a most unusual case, the above rule is sufficiently accurate.

Example.—Let ke be a 5° curve. Suppose the tangent $ef = 1632$ feet, and the distance $gf = 42$ feet,

Then $\frac{42}{1632} = .0257 = \text{nat. tang. of } 1^\circ 28'$. Reducing

minutes to hundredths, and dividing by 5° , we have 29 feet, the distance back to the correct P. T.

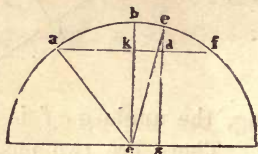
Should the curves turn in the same direction, or should e be a fixed point from which to run a tangent to $g b$, the above illustration is still applicable.

ARTICLE XXI.

ORDINATES.

TO FIND THE MIDDLE ORDINATE TO ANY GIVEN CHORD, IN A CURVE OF ANY GIVEN RADIUS.

1st. (See figure in Art. XVI.) $k c = \sqrt{a c^2 - a k^2}$, and $a c$ or $b c - k c =$ the ordinate required. That is, from the square of the radius subtract the square of half the chord, and take the square root of the remainder from radius, for the middle ordinate.



Example.—The radius $a c$ being 819 feet, and the chord $a f$ 100 feet, to find the middle ordinate, $b k$.

Here $a c^2 - a k^2 = 670761 - 2500, = 668261$, the square root of which is $c k, = 817.5$, which taken from radius 819, leaves 1.5, the required middle ordinate.

2d. Subtract the nat. cosine of the tangential angle from 1, and multiply the remainder by radius.

Example.—Suppose ab a 7° curve. Here the nat. cosine of $3^\circ 30'$, the tangential angle, is $\cdot 9981$, which, subtracted from 1, leaves $\cdot 0019$. Multiplying this latter by radius 819, we have $1\cdot 5$, the middle ordinate as before

HAVING GIVEN THE MIDDLE ORDINATE, TO FIND ANY OTHER.

1st. $eg = \sqrt{ce^2 - cg^2}$, and $ed = eg - gd$ or ck .

Example.—Suppose the distance kd or cg to be 20 feet. Thence $ce^2 - cg^2 = 670761 - 400 = 670361$, the square root of which is $eg = 818\cdot 76$. Taking from this the distance $gd = 817\cdot 5$, we have the ordinate $ed = 1\cdot 26$.

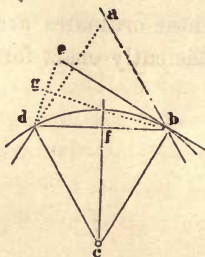
2d. Multiply the ordinates of a 1° curve by the deflexion angle of the curve whose ordinates are required. This is an approximation sufficiently exact for railway curves.

ARTICLE XXII.

TO FIND THE RADIUS CORRESPONDING TO ANY DEFLEXION ANGLE, AND TO EQUAL CHORDS OF ANY GIVEN LENGTH.

HERE the deflexion angle, $d b a$, is of course equal to the central angle $d c b$, subtended by the given chord $d b$, and the triangle $c d b$ being isosceles we have $\frac{180^\circ - d c b}{2} = c d b$, or $d b c$.

Then $\text{nat. sin. } d c b : \text{nat. sin. } c b d :: d b : c d$, the radius.



Example.—Let the deflexion angle be 5° , and the chord 100 feet. Required the radius. The nat. sine of $5^\circ = .0872$ and $\frac{180^\circ - 5^\circ}{2} = 87^\circ 30'$, the nat. sine of which is .9990.

Then $.0872 : .9990 :: 100 : \text{radius} = 1146$ feet.

An approximate result, sufficiently accurate for all purposes of railway location, may be found by simply dividing 5730 by the deflexion angle.

To find the deflexion angle corresponding to any given

radius and chord.—In this case, we have $cd : df :: \text{rad of } 1 : \text{nat. sin. of half the deflexion angle}$; therefore, divide half of the chord by the radius of the curve; the quotient will be the nat. sine of half the deflexion angle.

Example.—Radius as before 1146 feet, and chord 100 feet. Then $\frac{50}{1146} = .0436$, the nat. sin. of $2^\circ 30'$. Doubling this result we have the deflexion angle, viz. $5^\circ 00'$.

To find the deflexion distance with chord of 100 feet and any radius.—Divide the constant number 10000 by the radius in feet; the quotient will be the deflexion distance:—for the deflexion distance with a radius of 10000 feet is 1 foot, and the deflexion distances for other radii increase inversely as the radii.

Example.—What is the deflexion distance for a 5° curve, the chord being 100 feet? Here $\frac{10000}{1146} = 8.72$ feet, the deflexion distance.

To find the deflexion distance with any given chord and radius.—The deflexion distance is equal to twice the natural sine of half the *deflexion* angle, multiplied by the chord. Thus, the chord being 100 feet, and the deflexion angle 5° , we find the nat. sine of $2^\circ 30'$ equal to .0436, which doubled, and multiplied by 100, gives 8.72 feet, as above.

The tangential distance, with any radius and chord, is in like manner equal to twice the nat. sine of half the tangential angle multiplied by the chord. Thus, the tangential angle being $2^\circ 30'$ and the chord 100 feet, we find the nat. sine of $1^\circ 15' = .0218$. Multiplying by 2, and 100, we have 4.36 feet, the tangential distance.

For all curves under 11° , the tangential distance is equal to half the deflexion distance.

ARTICLE XXIII.

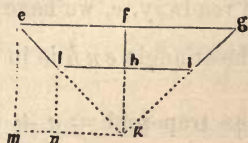
OF EXCAVATION AND EMBANKMENT.

A RAILWAY line having been located, the first office duties are to map it down, to make a continuous profile, and an approximate estimate of the cost of grading, &c. The "elevation" of each stake above or below a certain assumed base being fixed, the profile is drawn, on paper prepared for the purpose, to a horizontal scale of 400 feet, and a vertical scale of 40 feet, to the inch. This distorted picture presents at a glance, in compact shape, the undulations of the surface, and from it grades are adopted, to balance as nearly as possible the excavation and embankment. By these grades, noted in the record, the cutting or filling is ascertained at each station. Suppose, for instance, that the elevation of station 40 is 12 feet, and that of station 100 is 72 feet. The distance between 40 and 100 is 6000 feet, and the difference between 12 and 72 is 60 feet. Consequently, to connect those points, we require an ascending grade of 1 in 100 feet. Grade at station 54 is therefore 26 feet, and at station 60, 32 feet. If the elevation at station 60 be 38 feet, of course we have 6 feet of excavation, and this is marked in our estimate sheets + 6. If the elevation at that point should be 27 feet, 5 feet of embankment is the consequence, which is marked accordingly, — 5; *plus* indicating excavation, and *minus* embankment.

The usual slope for embankment is $1\frac{1}{2}$ feet horizontal to 1 foot vertical, making an angle of about 34° with the

horizon; that for earth cut, 1 to 1, or 45° , and for rock cut $\frac{1}{4}$ to 1, or 76° . The slopes of the ground surface at each station being known, together with the breadth of the intended roadway, we are prepared to calculate the cross-sectional areas, and from them to determine the cubic yards of excavation and embankment.

To facilitate these operations the following rules were prepared. With Trautwine's common diagram, and the table of squares and square roots appended to the volume, they will be found an observable assistance.



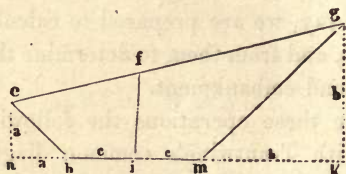
Suppose li the road bed, and fh the depth of an ordinary clay cut. Produce the side slopes until they meet in the point k . Then the angle being 45° , $ef = fk$, and $ef^2 =$ twice the triangle efk , $=$ the triangle ekg . For like reasons $lh = hk$, and $lh^2 =$ triangle lki . But the triangle lki , taken from the triangle ekg , leaves the area elg , to find which we have therefore the following

Rule.—To half the breadth of the roadway, add the depth of the cut. From the square of this sum, subtract the square of half the breadth of the roadway for the area.

Example.—Suppose the breadth of the roadway to be 32 feet, and the depth hf , 7 feet. Half of 32 $=$ 16, the square of which, viz., 256, becomes a constant subtrahend. $16 + 7 = 23$, and a reference to the table shows the square of 23 equal to 529. Therefore $529 - 256 = 273$, the area required in square feet.

If there be a regular slope, as eg (p. 58), we can plot it on the diagram, and read at once the side cuts, gk , en . Then

the area is equal to that of the trapezoid $enkg$, minus the two triangles $en h$, $mk g$.



Calling en , or its equal nh , a , mk or gk , b , and half the breadth of the roadway, c , we have the triangle $mk g$

$$= b \times \frac{b}{2} = \frac{b^2}{2}.$$

The triangle $en h$ is in like manner $= \frac{a^2}{2}$,

and the area of the trapezoid $= a + b + 2c \times \frac{a+b}{2}$.

$$\begin{aligned} \text{Then the area required} &= a + b + 2c \times \frac{a+b}{2} - \frac{a^2 + b^2}{2} \\ &= \frac{a^2 + 2ab + 2ac + 2bc + b^2}{2} - \frac{a^2 + b^2}{2} \\ &= \frac{2ab + 2ac + 2bc}{2} = (a+b)c + ab. \end{aligned}$$

Should the slopes be $\frac{1}{4}$ to 1, as in rock cut, the area might, in similar-wise, be shown equal to $(a+b)c + \frac{a.b}{4}$, and that of embankment, where the slopes are $1\frac{1}{2}$ to 1, equal to $(a+b)c + \frac{3a.b}{2}$. Wherefore, we arrive at the

following general rule for finding cross-sectional areas, where the ground surface is a regular declivity :

Multiply the *sum* of the side cuttings by half the breadth of the roadway, and mark the product. Multiply the *product* of the side cuttings by the ratio of the side slopes to 1, and add this result to the previous product marked for the area.

Example 1.—Earth excavation—road bed 32 feet, side

slopes 1 to 1, right cutting 12 feet, left cutting 3 feet. Required the cross-sectional area. Here $(a + b) c + a b = (12 + 3) 16 + 12 \times 3 = 240 + 36 = 276$ square feet, the area required.

Example 2.—Rock cut—road bed 28 feet, side slopes $\frac{1}{4}$ to 1, cuttings as before. Required the area.

Here $(a + b) c + \frac{a \times b}{4} = 210 + \frac{36}{4} = 219$ square

feet, the area.

Example 3.—Embankment—roadway 27 feet, side slopes $1\frac{1}{2}$ to 1, cuttings as before. Here $(a + b) c +$

$\frac{3(a \times b)}{2} = 202.5 + 54 = 256.5$ square feet, the cross-

sectional area.

Other formulæ might be given for varying surface slopes, but they would involve a simple matter, and require more time for calculation than a division of the diagram area into triangles.

To find the cubic content of an excavation or embankment:—

Multiply half the sum of the two end areas by the distance between them; thus: supposing 282 and 310 to be the end areas, and 100 feet the distance, we have

$\frac{(282 + 310)}{2} \times 100 = 29600$ cubic feet = 1096.3 cubic

yards. Or we may multiply the sum of the end areas by 100, and divide the product by 6 and 9, the factors of 54, which is the number of cubic feet contained in two cubic

yards; thus, $\frac{59200}{6} = 9866.6$, and this divided by 9 =

1096.3, as above.

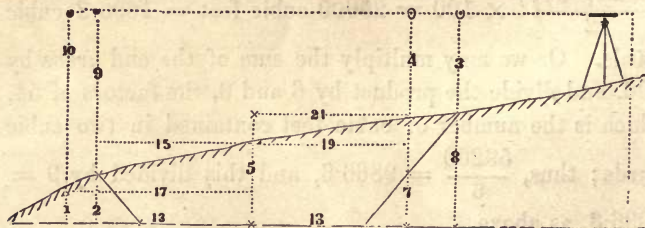
PRISMOIDAL FORMULA.

To the two end areas add four times the middle area, and multiply the sum by one-sixth of the length of the prismoid. Thus: from the foregoing example, the sum of the end areas, 592, added to four times their mean, 1184, gives 1776, and $1776 \times 16.7 = 29659.2$ cubic feet, = 1098.5 cubic yards. The former rule is approximate—sufficiently so for rough preliminary calculations, but where strict correctness is required, as in a final field estimate, the prismoidal formula should be used. It applies to all solid bodies with plane faces and parallel ends.

ARTICLE XXIV.

SIDE STAKING.

THE object in side staking is to find the point where the surface of the ground intersects the slope of the road



formation. For performing this work with level and rod, place the instrument in such a position as to command as many stations as possible, whether they be on the upper

or lower side, and ascertain by transfers from the bench the height of your instrument with reference to grade. This will facilitate operations by giving usually small numbers to work with. Knowing your rate of grade, subtract or add, as the case may be, as you change from station to station.

Having the level in place, we will suppose on an excavation, our object is first to place the lower side stake. Let the width of the road bed be 26 feet, and the side slopes 1 to 1. Suppose the instrument to be 11 feet above grade and the centre cut 5 feet, which latter is already recorded in the field book for construction duties. Looking at the fall of the hill we judge that at the distance of 17 feet from the centre stake the descent is 1.5 feet, which would give us 3.5 feet cutting. We take an observation at that point and find that the rod reads 10 feet, which, subtracted from our height above grade, leaves us only one foot cutting, and shows that our judgment has been at fault. The distance measured is too much, for were we to increase the distance we would reduce the cutting, and it is therefore evident that we are too far from the centre. Let us then make the distance from the centre stake 15 feet, and take another sight, when the rod reads 9, showing 2 feet cutting, which, added to half the road formation, slope being 1 to 1, equals the distance measured. The stake is therefore correct. The same process applies to the upper side.

The only difference in staking out for banks is that you add $1\frac{1}{2}$ times the height of the bank to the distance measured, or, as a general rule, the height of the bank multiplied by the ratio of the side slopes to unity.

Some judgment is required to be expeditious in this work, which is obtained only by experience.

The following is a common form of field record for construction :

						Left Side.		Centre.		Right Side	
Sta	Dist.	Course.	Mag. Course.	Elevation	Grade.	Dist.	A or B	A	B	Dist.	A or B
530	100	N 20°00' W	N 20°05' W	+ 560.4	+ 555.4	15.0	2.0 A	5.0		21.0	8.0 A

NATURAL SINES AND TANGENTS.

(63)

	0°	1°	2°	3°	4°	5°	6°	7°	
0	000 0000	017 4524	034 8995	052 3360	069 7565	087 1557	104 5285	121 8693	60
1	2909	7432	035 1902	6264	070 0467	4455	8178	122 1581	59
2	5818	018 0341	4809	9169	3368	7353	105 1070	4468	58
3	8727	3249	7716	053 2074	6270	088 0251	3963	7355	57
4	001 1636	6158	036 0623	4979	9171	3148	6856	123 0241	56
5	4544	9066	3530	7883	071 2073	6046	9748	312~	55
6	7453	019 1974	6437	054 0788	4974	8943	106 2641	6015	54
7	002 0362	4883	9344	3693	7876	089 1840	5533	8901	53
8	3271	7791	037 2251	6597	072 0777	4738	8425	124 1788	52
9	6180	020 0699	5158	9502	3678	7635	107 1318	4674	51
10	9089	3608	8065	055 2406	6580	090 0532	4210	7560	50
11	003 1998	6516	038 0971	5311	9481	3429	7102	125 0446	49
12	4907	9424	3878	8215	073 2382	6326	9994	3332	48
13	7815	021 2332	6785	056 1119	5283	9223	108 2885	6218	47
14	004 0724	5241	9692	4024	8184	091 2119	5777	9104	46
15	3633	8149	039 2598	6928	074 1085	5016	8669	126 1990	45
16	6542	022 1057	5505	9832	3986	7913	109 1560	4875	44
17	9451	3965	8411	057 2736	6887	092 0809	4452	7761	43
18	005 2360	6873	040 0318	5640	9787	3706	7343	127 0646	42
19	5268	9781	~ 4224	8544	075 2688	6602	110 0234	3531	41
20	8177	023 2690	7131	058 1448	5589	9499	3126	6416	40
21	006 1086	5598	041 0037	4352	8489	093 2395	6017	9302	39
22	3995	8506	2944	7256	076 1390	5291	8908	128 2186	38
23	6904	024 1414	5850	059 0160	4290	8187	111 1799	5071	37
24	9813	4322	8757	3064	7190	094 1083	4689	7956	36
25	007 2721	7230	042 1663	5967	077 0091	3979	7580	129 0841	35
26	5630	025 0138	4569	8871	2991	6875	112 0471	3725	34
27	8539	3046	7475	060 1775	5891	9771	3361	6609	33
28	008 1448	5954	043 0382	4678	8791	095 2~66	6252	9494	32
29	4357	8862	3288	7582	078 1691	5562	9142	130 2378	31
30	7265	026 1769	6194	061 0485	4591	8458	113 2032	5262	30
31	009 0174	4677	9100	3389	7491	096 1353	4922	8146	29
32	3083	7585	044 2006	6292	079 0391	4248	7812	131 1030	28
33	5992	027 0493	4912	9196	3290	7144	114 0702	3913	27
34	8900	3401	7818	062 2099	6190	097 0039	3592	6797	26
35	010 1809	6309	045 0724	5002	9090	2934	6482	9681	25
36	4718	9216	3630	7905	080 1989	5829	9372	132 2564	24
37	7627	028 2124	6536	063 0808	4889	8724	115 2261	5447	23
38	011 0535	5032	9442	3711	7788	098 1619	5151	8330	22
39	3444	7940	046 2347	6614	081 0687	4514	8040	133 1213	21
40	6353	029 0847	5253	9517	3587	7408	116 0929	4096	20
41	9261	3755	8159	064 2420	6486	099 0303	3818	6979	19
42	012 2170	6662	047 1065	5323	9385	3197	6707	9862	18
43	5079	9570	3970	8226	082 2284	6092	9596	134 2744	17
44	7987	030 2478	6876	065 1129	5183	8986	117 2485	5627	16
45	013 0896	5385	9781	4031	8082	100 1881	5374	8509	15
46	3805	8293	048 2687	6934	083 0981	4775	8263	135 1392	14
47	6713	031 1200	5592	9836	3880	7669	118 1151	4274	13
48	9622	4108	8498	066 2739	6778	101 0563	4040	7156	12
49	014 2530	7015	049 1403	5641	9677	3457	6928	136 0038	11
50	5439	9922	4308	8544	084 2576	6351	9816	2919	10
51	8348	032 2830	7214	067 1446	5474	9245	119 2704	5801	9
52	015 1256	5737	050 0119	4349	8373	102 2138	5593	8683	8
53	4165	8644	3024	7251	085 1271	5032	8481	137 1564	7
54	7073	033 1552	5929	068 0153	4169	7925	120 1368	4445	6
55	9982	4459	8835	3055	7067	103 0819	4256	7327	5
56	016 2890	7366	051 1740	5957	9966	3712	7144	138 0208	4
57	5799	034 0274	4645	8859	086 2864	6605	121 0031	3089	3
58	8707	3181	7550	069 1761	5762	9499	2919	5970	2
59	017 1616	6088	052 0455	4663	8660	104 2392	5806	8850	1
60	4524	8995	3360	7565	087 1557	5285	8693	139 1731	0
	89°	88°	87°	86°	85°	84°	83°	82°	

	0°	1°	2°	3°	4°	5°	6°	7°	
0	000 0000	017 4551	034 9208	052 4078	069 9268	087 4887	105 1042	122 7840	60
1	2909	7460	035 2120	6995	070 2191	7818	3983	123 0798	59
2	5818	018 0370	5033	9912	5115	088 0749	6925	3752	58
3	8727	3250	7945	053 2829	8038	3681	9866	6708	57
4	001 1636	6190	036 0858	5746	071 0961	6612	106 2808	9658	56
5	4544	9100	3771	8663	3885	9544	5750	124 2612	55
6	7453	019 2010	6683	054 1581	6809	089 2476	8692	5566	54
7	002 0362	4920	9596	4498	9733	5408	107 1634	8520	53
8	3271	7830	037 2509	7416	072 2657	8341	4576	125 1474	52
9	6180	020 0740	5422	055 0333	5581	090 1273	7519	4429	51
10	9089	3650	8335	3251	8505	4200	108 0462	7384	50
11	003 1938	6560	038 1248	6169	073 1430	7138	3405	126 0339	49
12	4907	9470	4161	9087	4354	091 0071	6348	3294	48
13	7816	021 2380	7074	056 2005	7279	3004	9291	6249	47
14	004 0725	5291	9983	4923	074 0203	5938	109 2234	9205	46
15	3634	8201	039 2901	7841	3128	8871	5178	127 2161	45
16	6542	022 1111	5814	057 0759	6053	092 1804	8122	5117	44
17	9451	4021	8728	3678	8979	4738	110 1066	8073	43
18	005 2360	6932	040 1641	6596	075 1904	7672	4010	128 1030	42
19	5269	9842	4555	9515	4829	093 0606	6955	3986	41
20	8178	023 2753	7469	058 2434	7755	3540	9899	6943	40
21	006 1087	5663	041 0383	5352	076 0680	6474	111 2844	9900	39
22	3996	8574	3296	8271	3606	9409	5789	129 2858	38
23	6905	024 1484	6210	059 1190	6532	094 2344	8734	5815	37
24	9814	4395	9124	4109	9458	5278	112 1680	8773	36
25	007 2723	7305	042 2038	7029	077 2384	8213	4625	130 1731	35
26	5632	025 0216	4952	9948	5311	095 1148	7571	4690	34
27	8541	3127	7866	060 2867	8237	4084	113 0517	7648	33
28	008 1450	6038	043 0781	5787	078 1164	7019	3463	131 0607	32
29	4360	8948	3695	8706	4096	9955	6410	3566	31
30	7269	026 1859	6609	061 1626	7017	096 2890	9356	6525	30
31	009 0178	4770	9524	4546	9944	5826	114 2303	9484	29
32	3087	7681	044 2438	7466	079 2871	8763	5250	132 2444	28
33	5996	027 0592	5353	062 0386	5798	097 1699	8197	5404	27
34	8905	3503	8268	3306	8726	4635	115 1144	8364	26
35	010 1814	6414	045 1183	6226	080 1653	7572	4092	133 1324	25
36	4724	9325	4097	9147	4581	098 0509	7039	4285	24
37	7633	028 2236	7012	063 2067	7509	3446	9987	7246	23
38	011 0542	5148	9927	4988	081 0437	6383	116 2936	134 0207	22
39	3451	8059	046 2842	7908	3365	9320	5884	3168	21
40	6361	029 0970	5757	064 0829	6293	099 2257	8832	6129	20
41	9270	3882	8673	3750	9221	5194	117 1781	9091	19
42	012 2179	6793	047 1588	6671	082 2150	8133	4730	135 2053	18
43	5088	9705	4503	9592	5078	100 1071	7679	5015	17
44	7998	030 2616	7419	065 2513	8007	4009	118 0628	7978	16
45	013 0907	5528	048 0334	5435	083 0936	6947	3578	136 0940	15
46	3817	8439	3250	8356	3865	9886	6528	3903	14
47	6726	031 1351	6166	066 1278	6794	101 2824	9478	6866	13
48	9635	4263	9082	4199	9723	5763	119 2428	9830	12
49	014 2545	7174	049 1997	7121	084 2653	8702	5378	137 2793	11
50	5454	032 0086	4913	067 0043	5583	102 1641	8329	5757	10
51	8364	2998	7829	2965	8512	4580	120 1279	8721	9
52	015 1273	5910	050 0746	5887	085 1442	7520	4230	138 1685	8
53	4183	8822	3662	8809	4372	103 0460	7182	4650	7
54	7093	033 1734	6578	068 1732	7302	3399	121 0133	7615	6
55	016 0002	4646	9495	4654	086 0233	6340	3085	139 0580	5
56	2912	7558	051 2411	7577	3163	9280	6036	3545	4
57	5821	034 0471	5328	069 0499	6094	104 2220	89 8	6510	3
58	8731	3383	8244	3422	9025	5161	122 1941	9476	2
59	017 1641	6295	052 1161	6345	087 1956	8101	4893	140 2442	1
60	4551	9208	4078	9268	4887	105 1042	7846	5408	0
	89°	88°	87°	86°	85°	84°	83°	82°	

	8°	9°	10°	11°	12°	13°	14°	15°	
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1	4612	7218	9346	191 0945	208 1962	225 2345	242 2041	259 1006	59
2	7492	157 0091	174 2211	3801	4807	5179	4863	3810	58
3	140 0372	2963	5075	6656	7652	8013	7685	6619	57
4	3252	5836	7939	9510	209 0497	226 0846	243 0507	9428	56
5	6132	8708	175 0803	192 2365	3341	3680	3329	260 2237	55
6	9012	158 1581	3667	5220	6186	6513	6150	5045	54
7	141 1892	4453	6531	8074	9030	9346	8971	7853	53
8	4772	7325	9395	193 0928	210 1874	227 2179	244 1792	261 0662	52
9	7651	159 0197	176 2258	3782	4718	5012	4613	3469	51
10	142 0531	3069	5121	6636	7561	7844	7433	6277	50
11	3410	5940	7984	9490	211 0405	228 0677	245 0254	9085	49
12	6289	8812	177 0847	194 2344	3248	3509	3074	262 1892	48
13	9168	160 1683	3710	5197	6091	6341	5894	4699	47
14	143 2047	4555	6573	8050	8934	9172	8713	7506	46
15	4926	7426	9435	195 0903	212 1777	229 2004	246 1533	263 0312	45
16	7805	161 0297	178 2298	3756	4619	4835	4352	3118	44
17	144 0684	3167	5160	6609	7462	7666	7171	5925	43
18	3562	6038	8022	9461	213 0304	230 0497	2990	8730	42
19	6440	8909	179 0884	196 2314	3146	3328	247 2809	264 1536	41
20	9319	162 1779	3746	5166	5988	6159	5627	4342	40
21	145 2197	4650	6607	8018	8829	8989	8445	7147	39
22	5075	7520	9469	197 0870	214 1671	231 1819	248 1263	9952	38
23	7953	163 0390	180 2330	3722	4512	4649	4081	265 2757	37
24	146 0830	3260	5191	6573	7353	7479	6899	5561	36
25	3708	6129	8052	9425	215 0194	232 0309	9716	8366	35
26	6585	8999	181 0913	198 2276	3035	3138	249 2533	266 1170	34
27	9463	164 1868	3774	5127	5376	5967	5350	3973	33
28	147 2340	4738	6635	7978	8716	8796	8167	6777	32
29	5217	7607	9495	199 0829	216 1556	233 1625	250 0984	9581	31
30	8094	165 0476	182 2355	3679	4396	4454	3800	267 2384	30
31	148 0971	3345	5215	6530	7236	7282	6616	5187	29
32	3848	6214	8075	9380	217 0076	234 0110	9432	7989	28
33	6724	9082	183 0935	200 2230	2915	2938	251 2248	268 0792	27
34	9601	166 1951	3795	5080	5754	5766	5063	3594	26
35	149 2477	4819	6654	7930	8593	8594	7879	6396	25
36	5353	7687	9514	201 0779	218 1432	235 1421	252 0694	9198	24
37	8230	167 0556	184 2373	3629	4271	4248	3508	269 2000	23
38	150 1106	3423	5232	6478	7110	7075	6323	4801	22
39	3981	6291	8091	9327	9948	9902	9137	7602	21
40	6857	9159	185 0949	202 2176	219 2786	236 2729	253 1952	270 0403	20
41	9733	168 2026	3808	5024	5624	5555	4766	3204	19
42	151 2608	4894	6666	7873	8462	8381	7579	6004	18
43	5484	7761	9524	203 0721	220 1300	237 1207	254 0393	8805	17
44	8359	169 0628	186 2382	3569	4137	4033	3206	271 1605	16
45	152 1234	3495	5240	6418	6974	6859	6019	4404	15
46	4109	6362	8098	9265	9811	9684	8832	7204	14
47	6984	9228	187 0956	204 2113	221 2648	238 2510	255 1645	272 0003	13
48	9858	170 2095	3813	4961	5485	5335	4458	2802	12
49	153 2733	4961	6670	7808	8321	8159	7270	5601	11
50	5607	7828	9528	205 0655	222 1158	239 0984	256 0082	8400	10
51	8482	171 0694	188 2385	3502	3994	3808	2894	273 1198	9
52	154 1356	3560	5241	6349	6830	6633	5705	3997	8
53	4230	6425	8098	9195	9666	9457	8517	6794	7
54	7104	9291	189 0954	206 2042	223 2501	240 2280	257 1328	9592	6
55	9978	172 2156	3811	4888	5337	5104	4139	274 2390	5
56	155 2851	5022	6667	7734	8172	7927	6950	5187	4
57	5725	7887	9523	207 0580	224 1007	241 0751	9760	7984	3
58	8598	173 0752	190 2379	3426	3842	3574	258 2570	275 0781	2
59	156 1472	3617	5234	6272	6676	6396	5381	3577	1
60	4345	6482	8090	9117	9511	9219	8190	6374	0
	81°	80°	79°	78°	77°	76°	75°	74°	

	8°	9°	10°	11°	12°	13°	14°	15°	
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1	8375	6826	6209	6822	8606	231 1740	6370	268 2610	59
2	141 1342	9809	9269	9841	213 1647	4811	9460	5728	58
3	4308	159 2791	177 2269	195 2861	4688	7876	250 2551	8847	57
4	7276	5774	5270	5881	7730	232 0941	5642	269 1967	56
5	142 0243	8757	8270	8901	214 0772	4007	8734	5087	55
6	3211	160 1740	178 1271	196 1922	3814	7073	251 1826	8207	54
7	6179	4724	4273	4943	6857	233 0140	4919	270 1328	53
8	9147	7708	7274	7964	9900	3207	8012	4449	52
9	143 2115	161 0692	179 0276	197 0986	215 2944	6274	252 1106	7571	51
10	5084	3677	3279	4008	5988	9342	4200	271 0694	50
11	8053	6662	6281	7031	9032	234 2410	7294	3817	49
12	144 1022	9647	9284	10053	216 2077	5479	253 0389	6940	48
13	3991	162 2632	180 2287	3076	5122	8548	3484	272 0064	47
14	6961	5618	5291	6100	8167	235 1617	6580	3186	46
15	9931	8603	8295	9124	217 1213	4687	9676	6313	45
16	145 2901	163 1590	181 1299	199 2148	4259	7758	254 2773	9438	44
17	5872	4576	4303	5172	7306	236 0829	5870	273 2564	43
18	8842	7563	7308	8197	218 0353	3900	8968	5690	42
19	146 1813	164 0550	182 0313	200 1222	3400	6971	255 2066	8817	41
20	4784	3537	3319	4248	6448	237 0044	5165	274 1945	40
21	7756	6525	6324	7274	9496	3116	8264	5072	39
22	147 0727	9513	9330	201 0300	219 2544	6189	256 1363	8201	38
23	3699	165 2501	183 2337	3327	5593	9262	4463	275 1330	37
24	6672	5489	5343	6354	8643	238 2336	7564	4459	36
25	9644	8478	8350	9381	220 1692	5410	257 0664	7589	35
26	148 2617	166 1467	184 1358	202 2409	4742	8485	3766	276 0719	34
27	5590	4456	4365	5437	7793	239 1560	6868	3850	33
28	8563	7446	7373	8465	221 0844	4635	9970	6981	32
29	149 1536	167 0436	185 0382	203 1494	3895	7711	258 3073	277 0113	31
30	4510	3426	3390	4523	6947	240 0788	6176	3245	30
31	7484	6417	6399	7552	9999	3864	9280	6378	29
32	150 0458	9407	9409	204 0582	222 3051	6942	259 2384	9512	28
33	3433	168 2398	186 2418	3612	6104	241 0019	5498	278 2646	27
34	6408	5390	5428	6643	9157	3097	8593	5780	26
35	9383	8381	8439	9674	223 2211	6170	260 1699	8915	25
36	151 2358	169 1373	187 1449	205 2705	5265	9255	4805	279 2050	24
37	5333	4366	4460	5737	8319	242 2334	7911	5180	23
38	8309	7358	7471	8769	224 1374	5414	261 1018	8322	22
39	152 1285	170 0351	188 0483	206 1801	4429	8494	4126	280 1459	21
40	4262	3344	3495	4834	7485	243 1575	7234	4597	20
41	7238	6338	6507	7867	225 0541	4656	262 0342	7735	19
42	153 0215	9331	9520	207 0900	3597	7737	3451	281 0873	18
43	3192	171 2325	189 2533	3934	6654	244 0819	6560	4012	17
44	6170	5320	5546	6968	9711	3902	9070	7152	16
45	9147	8314	8558	208 0003	226 2769	6984	263 2780	282 0292	15
46	154 2125	172 1309	190 1573	3038	5827	245 0068	5891	3432	14
47	5103	4304	4587	6073	8885	3151	9002	6573	13
48	8082	7300	7602	9109	227 1944	6236	264 2114	9715	12
49	155 1061	173 0296	191 0617	209 2145	5003	9320	5226	283 2857	11
50	4040	3292	3632	5181	8063	246 2405	8339	5999	10
51	7019	6288	6648	8218	228 1123	5491	265 1452	9143	9
52	9998	9285	9664	210 1255	4184	8577	4566	284 2286	8
53	156 2978	174 2282	192 2680	4293	7244	247 1663	7680	5430	7
54	5958	5279	5690	7331	229 0306	4750	266 0794	8575	6
55	8939	8277	8713	211 0369	3367	7837	3909	285 1720	5
56	157 1919	175 1275	193 1731	3407	6429	248 0925	7025	4866	4
57	4900	4273	4748	6446	9492	4013	267 0141	8012	3
58	7881	7272	7760	9486	230 2555	7102	3257	286 1159	2
59	158 0955	176 0271	194 0784	212 2525	5618	249 0191	6374	4300	1
60	3844	3270	3803	5566	8682	3280	9492	7454	0
	81°	80°	79°	78°	77°	76°	75°	74°	

	16°	17°	18°	19°	20°	21°	22°	23°	
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2	276 1965	9280	5702	326 1182	5668	9110	375 1459	391 2666	58
3	4761	293 2061	8468	3932	8400	359 1825	4156	5343	57
4	7556	4842	310 1234	6681	343 1133	4540	6852	8019	56
5	277 0352	7623	3999	9450	3865	7254	9547	392 0695	55
6	3147	294 0403	6764	327 2179	6597	9968	376 2243	3371	54
7	5941	3183	9529	4928	9329	360 2682	4938	6047	53
8	8736	5963	311 2294	7676	344 2060	5395	7632	9722	52
9	278 1530	8743	5058	328 0424	4791	8108	377 0327	397 1397	51
10	4324	295 1522	7822	3172	7521	361 0821	3021	4071	50
11	7118	4302	312 0586	5919	345 0252	3534	5714	6745	49
12	9911	7081	3349	8666	2982	6246	8408	9419	48
13	279 2704	9859	6112	329 1413	5712	8958	378 1101	394 2093	47
14	5497	296 2638	8875	4160	8441	362 1669	3794	4766	46
15	8290	5416	313 1638	6906	346 1171	4380	6486	7439	45
16	280 1083	8194	4400	9653	3900	7091	9178	395 0111	44
17	3875	297 0971	7163	320 2398	6628	9802	379 1870	2783	43
18	6667	3749	9925	5144	9357	363 2512	4562	5455	42
19	9459	6526	314 2686	7889	347 2085	5222	7253	8127	41
20	281 2251	9303	5448	331 0634	4812	7932	9944	396 0798	40
21	5042	298 2079	8209	3379	7540	364 0641	380 2634	3468	39
22	7833	4856	315 0969	6123	348 0267	3351	5324	6139	38
23	282 0624	7632	3730	8867	2994	6059	8014	8809	37
24	3415	299 0408	6490	332 1611	5720	8768	381 0704	397 1479	36
25	6205	3184	9250	4355	8447	365 1476	3393	4148	35
26	8995	5959	316 2010	7098	349 1173	4184	6082	6818	34
27	283 1785	8734	4770	9841	3898	6891	8770	9486	33
28	4575	300 1509	7529	333 2584	6624	9599	382 1459	398 2155	32
29	7364	4284	317 0288	5326	9349	366 2306	4147	4823	31
30	284 0153	7058	3047	8069	350 2074	5012	6834	7491	30
31	2942	9832	5805	334 0810	4798	7719	9522	399 0158	29
32	5731	301 2606	8563	3552	7523	367 0425	383 2209	2925	28
33	8520	5380	318 1321	6293	351 0246	3130	4895	5492	27
34	285 1308	8153	4079	9034	2970	5836	7582	8158	26
35	4096	302 0926	6836	335 1775	5963	8541	384 0208	400 0825	25
36	6884	3699	9593	4516	8416	368 1246	2953	3490	24
37	9671	6471	319 2350	7256	352 1139	3950	5639	6156	23
38	286 2458	9244	5106	9996	3862	6654	8324	8821	22
39	5246	303 2016	7863	336 2735	6584	9358	385 1008	401 1486	21
40	8032	4788	320 0619	5475	9306	369 2061	3693	4150	20
41	287 0819	7559	3374	8214	353 2027	4765	6377	6814	19
42	3605	304 0331	6130	337 0953	4748	7468	9060	9478	18
43	6391	3102	8885	3691	7469	370 0170	386 1744	402 2141	17
44	9177	5872	321 1640	6429	354 0190	2872	4427	4804	16
45	288 1963	8643	4395	9167	2910	5574	7110	7467	15
46	4748	305 1413	7149	338 1905	5630	8276	9792	403 0129	14
47	7533	4183	9903	4642	8350	371 0977	387 2474	2791	13
48	289 0318	6953	322 2657	7379	355 1070	3678	5156	5453	12
49	3103	9723	5411	339 0116	3785	6379	7837	8114	11
50	5887	306 2492	8164	2852	6508	9079	388 0518	404 077	10
51	8671	5261	323 0917	5589	9226	372 1780	3199	3436	9
52	390 1455	8030	3670	8325	356 1544	4479	5880	6096	8
53	4239	307 0798	6422	340 1060	4662	7179	8500	8750	7
54	7022	3566	9174	3796	7380	9878	389 1240	405 1416	6
55	9805	6334	324 1926	6531	357 0097	373 2577	3919	4075	5
56	291 2588	9102	4678	9265	2814	5275	6598	6734	4
57	5371	308 1869	7429	341 2000	5531	7973	9277	9393	3
58	8153	4636	325 0180	4734	8248	374 0671	390 1915	406 2051	2
59	292 0935	7403	2931	7468	358 0964	3369	4653	4709	1
60	3717	309 0170	5682	342 0201	3679	6066	7311	7366	0
	73°	72°	71°	70°	69°	68°	67°	66°	

	16°	17°	18°	19°	20°	21°	22°	23°	
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2	3751	3670	5630	9785	6292	5317	7031	425 1616	58
3	6900	6852	8848	345 3040	9588	8656	405 0417	5051	57
4	288 0050	307 0034	326 2066	346 6296	365 2885	385 1996	406 3804	426 8487	56
5	3201	3218	5284	9553	6182	5337	7191	426 1924	55
6	6352	6402	8504	346 2810	9480	8679	406 0579	5361	54
7	9503	9586	327 1724	6068	366 2779	386 2021	407 3968	427 8800	53
8	289 2655	308 2771	4944	9327	6079	5364	7358	427 2239	52
9	5808	5957	8165	347 2586	9379	8708	407 0748	5680	51
10	8961	9143	328 1387	5846	367 2680	387 2053	4139	9121	50
11	230 2114	309 2330	4610	9107	5981	5398	7531	428 2563	49
12	5269	5517	7833	348 2368	9284	8744	408 0924	6005	48
13	8423	8705	329 1056	5630	368 2587	388 2091	4318	9449	47
14	291 1578	310 1893	4281	8893	5890	5439	7713	429 2894	46
15	4734	5083	7505	349 2156	9195	8787	409 1108	6339	45
16	7890	8272	330 0731	5420	369 2500	389 2136	4504	9785	44
17	292 1047	311 1462	3957	8685	5806	5486	7901	430 3232	43
18	4205	4653	7184	350 1950	9112	8837	410 1299	6680	42
19	7363	7845	331 0411	5216	370 2420	330 2189	4697	431 0129	41
20	293 0521	312 1036	3639	8483	5728	5541	8097	3579	40
21	3680	4229	6868	351 1750	9036	8894	411 1497	7030	39
22	6839	7422	332 0097	5018	371 2346	391 2247	4898	432 0481	38
23	9999	313 0616	3327	8287	5656	5602	8300	3933	37
24	294 3160	3810	6557	352 1556	8967	8957	412 1703	7386	36
25	6321	7005	9788	4826	372 2278	392 2313	5106	433 0840	35
26	9483	314 0200	333 3020	8096	5590	5670	8510	4295	34
27	295 2645	3396	6252	353 1368	8903	9027	413 1915	7751	33
28	5808	6593	9485	4640	373 2217	393 2386	5321	434 1208	32
29	8971	9790	334 2719	7912	5532	5745	8728	4665	31
30	296 2135	315 2988	5953	354 1186	8847	9105	414 2136	8124	30
31	5209	6186	9188	4460	374 2163	394 2465	5544	435 1583	29
32	8464	9535	335 2424	7734	5479	5827	8953	5043	28
33	297 1630	316 2585	5660	355 1010	8797	9189	415 2363	8504	27
34	4796	5735	8396	4286	375 2115	395 2552	5774	435 1966	26
35	7962	8986	336 2134	7562	5433	5916	9186	5429	25
36	298 1129	317 2187	5372	356 0840	8753	9280	416 2598	8893	24
37	4297	5389	8610	4118	376 2073	396 2645	6012	437 2357	23
38	7465	8591	337 1850	7397	5394	6011	9426	5823	22
39	299 0634	318 1794	5090	357 0676	8716	9378	417 2841	9289	21
40	3803	4998	8330	3956	377 2038	397 2746	6257	438 2756	20
41	6973	8202	338 1571	7237	5361	6114	9673	6224	19
42	300 0144	319 1407	4815	358 0518	8685	9483	418 3091	9693	18
43	3315	4613	8056	3301	378 2010	398 2853	6509	439 3163	17
44	6486	7819	339 1299	7083	5335	6224	9928	6634	16
45	9658	320 1025	4543	359 0367	8661	9595	419 3348	440 0105	15
46	301 2831	4232	7787	3651	379 1988	399 2968	6769	3578	14
47	6004	7440	340 1032	6936	5315	6341	420 0190	7051	13
48	9178	321 0649	4278	360 0222	8644	9715	3613	441 0526	12
49	302 2352	3858	7524	3508	380 1973	400 3089	7036	4001	11
50	5527	7067	341 0771	6795	5302	6465	421 0460	7477	10
51	6703	322 0278	4019	361 0082	8633	9841	3885	442 0954	9
52	303 1879	3489	7267	3371	381 1964	401 3218	7311	4432	8
53	5055	6700	42 0516	6660	5296	6596	422 0738	7910	7
54	8232	9912	3765	9949	8629	9974	4165	443 1390	6
55	304 1410	323 3125	7015	362 3240	382 1962	402 3354	7594	4871	5
56	4588	6338	343 0266	6531	5296	6734	423 1023	8352	4
57	7767	9552	3518	9823	8631	403 0115	4453	444 1834	3
58	305 0946	324 2766	6770	363 3115	383 1967	3496	7884	5318	2
59	4126	5981	344 0023	6408	5303	6879	424 1316	8802	1
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	73°	72°	71°	70°	69°	68°	67°	66°	

	24°	25°	26°	27°	28°	29°	30°	31°	
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1	457 0024	8819	6326	454 2497	7284	485 0640	2519	2874	59
2	2681	423 1455	8940	5088	9852	3184	5037	5367	58
3	5337	4090	439 1553	7679	470 2419	5727	7556	7859	57
4	7993	6725	4166	455 0269	4986	8270	501 0073	516 0351	56
5	408 0649	9360	6779	2859	7553	486 0812	2591	2842	55
6	3305	424 1994	9392	5449	471 0119	3354	5107	5333	54
7	5960	4628	440 2004	8038	2685	5895	7624	7824	53
8	8615	7262	4615	456 0627	5250	8436	502 0140	517 0314	52
9	409 1269	9895	7227	3216	7815	487 0977	2655	2804	51
10	3923	425 2528	9838	5804	472 0390	3517	5170	5293	50
11	6577	5161	441 2448	8392	2944	6057	7685	7782	49
12	9230	7793	5059	457 0979	5508	8597	503 0199	518 0270	48
13	410 1883	426 0425	7668	3566	8071	488 1136	2713	2758	47
14	4536	3056	442 0278	6153	473 0634	3674	5227	5246	46
15	7189	5687	2887	8739	3197	6212	7740	7733	45
16	9841	8318	5496	458 1325	5759	8750	504 0252	519 0219	44
17	411 2492	427 0949	8104	3910	8321	489 1288	2765	2705	43
18	5144	3579	443 0712	6496	474 0882	3825	5276	5191	42
19	7795	6208	3319	9080	3443	6361	7788	7676	41
20	412 0445	8338	5927	459 1665	6004	8897	505 0298	520 0161	40
21	3096	28 1467	8534	4248	8564	490 1433	2909	2646	39
22	5745	4095	444 1140	6832	475 1124	3968	5319	5130	38
23	8395	6723	3746	9415	3583	6503	7828	7613	37
24	413 1044	9351	6352	460 1998	6242	9038	506 0338	521 0096	36
25	3693	429 1979	8957	4580	8801	491 1572	2846	2579	35
26	6342	4606	445 1562	7162	476 1359	4105	5355	5061	34
27	8990	7233	4167	9744	3917	6638	7863	7543	33
28	414 1638	9859	6771	461 2325	6474	9171	507 0370	522 0024	32
29	4285	430 2485	9375	4906	9031	492 1704	2877	2505	31
30	6932	5111	446 1978	7486	477 1588	4236	5384	4986	30
31	9579	7736	4581	462 0066	4144	6767	7890	7466	29
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33	4872	2986	9786	5225	9255	493 1829	2901	523 2424	27
34	7517	5610	447 2388	7804	478 1810	4359	5406	4903	26
35	416 0163	8234	4990	463 0382	4364	6839	7910	7381	25
36	2808	432 0857	7591	2960	6919	9419	509 0414	9859	24
37	5453	3481	448 0192	5538	9472	494 1948	2918	524 2336	23
38	8097	6103	2792	8115	479 2026	4476	5421	4813	22
39	417 0741	8726	5392	464 0692	4579	7005	7924	7290	21
40	3385	433 1348	7992	3269	7131	9532	510 0426	9766	20
41	6028	3970	449 0591	5345	9683	495 2060	2928	525 2241	19
42	8671	6591	3190	8420	480 2235	4587	5429	4717	18
43	418 1313	9212	5789	465 0996	4786	7113	7930	7191	17
44	3956	434 1832	8397	3571	7337	9639	511 0431	9665	16
45	6597	4453	450 0984	6145	9888	496 2165	2931	526 2139	15
46	9239	7072	3582	8719	481 2438	4690	5431	4613	14
47	419 1880	9692	6179	466 1293	4987	7215	7930	7085	13
48	4521	435 2311	8775	3866	7537	9740	512 0429	9558	12
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53	7719	5401	452 1753	6727	483 0277	498 2355	2916	528 1914	7
54	421 0358	8018	4347	9298	2824	4877	5413	4383	6
55	2996	437 0634	6941	468 1869	5370	7399	7908	6853	5
56	5634	3251	9535	4439	7916	9928	514 0404	9322	4
57	8272	5866	453 2128	7009	484 0462	499 2441	2899	529 1790	3
58	422 0909	8482	4721	9578	3007	4961	5393	4258	2
59	3546	438 1097	7313	469 2147	5552	7481	7887	6726	1
60	6183	3711	9905	4716	8096	500 0000	515 0381	9193	0
	65°	64°	63°	62°	61°	60°	59°	58°	

	21°	25°	26°	27°	28°	29°	30°	31°	
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2	5773	6618	488 0927	8919	532 0826	6894	7382	601 2566	59
3	9260	467 0161	4530	510 2585	4559	555 0698	578 1262	6527	58
4	446 2747	3705	8133	6252	8293	4504	5144	602 0490	57
5	6236	7250	489 1737	9919	533 2029	8311	9027	4454	56
6	9726	468 0796	5343	511 3588	5765	556 2119	579 2912	8419	55
7	447 3216	4342	8949	7259	9503	5929	6797	603 2386	54
8	6708	7890	490 2557	512 0930	534 3242	9739	590 0684	6354	53
9	448 0200	469 1439	6166	4602	6981	557 3551	4573	604 0323	52
10	3693	4988	9775	8275	535 0723	7364	8462	4294	51
11	7187	8539	491 3386	513 1950	4465	558 1179	581 2353	8266	50
12	449 0682	470 2090	6997	5625	8208	4994	6245	605 2240	49
13	4178	5643	492 0610	9302	536 1953	8811	582 0139	6215	48
14	7675	9196	4224	514 2980	5699	559 2629	4034	606 0192	47
15	450 1173	471 2751	7838	6658	9446	6449	7930	4170	46
16	4672	6306	493 1454	515 0338	537 3194	560 0269	583 1828	8149	45
17	8171	9863	5071	4019	6943	4091	5726	607 2130	44
18	451 1672	472 3420	8689	7702	538 0694	7914	9627	6112	43
19	5173	6978	494 2308	516 1385	4445	561 1738	584 3528	608 0095	42
20	8676	473 0538	5928	5069	8198	5564	7431	4080	41
21	452 2179	4098	9549	8755	539 1952	9391	585 1335	8067	40
22	5683	7659	495 3171	517 2441	5707	562 3219	5241	609 2054	39
23	9188	474 1222	6794	6129	9464	7048	9148	6043	38
24	453 2694	4785	496 0418	9818	540 3221	563 0879	586 3056	610 0034	37
25	6201	8349	4043	518 3508	6980	4710	6965	4020	36
26	9709	475 1914	7669	7199	541 0740	8543	587 0876	8019	35
27	454 3218	5481	497 1297	519 0891	4501	564 2378	4788	611 2014	34
28	6728	9048	4925	4584	8263	6213	8702	6011	33
29	455 0238	476 2616	8554	8278	542 2027	565 0050	588 2616	612 0008	32
30	3750	6185	498 2185	520 1974	5791	3888	6533	4007	31
31	7263	9755	5816	5671	9557	7728	589 0450	8008	30
32	456 0776	477 3326	9449	9368	543 3324	566 1568	4369	613 2010	29
33	42° 0	6899	499 3082	521 3067	7092	5410	8289	6013	28
34	7806	478 0472	6717	6767	544 0862	9254	590 2211	614 0018	27
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36	4839	7621	3989	4170	8404	6944	591 0058	8032	25
37	8357	479 1197	7627	7874	545 2177	568 0791	3984	615 2041	24
38	458 1877	4774	501 1266	523 1578	5951	4639	7910	6052	23
39	5397	8352	4906	5284	9727	8488	592 1839	616 0064	22
40	8918	480 1932	8547	8990	546 3503	569 2339	5768	4077	21
41	459 2439	5512	502 2189	524 2698	7281	6191	9699	8092	20
42	5962	9093	5832	6407	547 1060	570 0045	593 3632	617 2108	19
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44	460 3011	6258	503 3121	3829	8621	7755	594 1501	618 0145	17
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46	461 0063	482 3427	504 0415	526 1255	6188	5471	9375	8188	15
47	3591	7014	4063	4969	9973	9331	595 3314	619 2211	14
48	7119	483 0601	7713	8685	549 3759	572 3192	7255	6236	13
49	462 0649	4189	505 1363	527 2402	7547	7054	596 1196	620 0263	12
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51	7710	484 1368	8668	9839	5125	4783	9084	8320	10
52	463 1243	4959	506 2322	528 3560	8916	8649	597 3030	621 2351	9
53	4776	8552	5977	7281	551 2708	574 2516	6978	6383	8
54	8310	485 2145	9633	529 1004	6502	6385	598 0926	622 0417	7
55	464 1845	5739	507 3290	4727	552 0297	575 0255	4877	4452	6
56	5352	9334	6948	8452	4093	4126	8828	8488	5
57	8919	486 2931	508 0607	530 2178	7890	7999	599 2781	623 2527	4
58	465 2457	6528	4267	5906	553 1688	576 1873	6735	6566	3
59	5996	487 0126	7929	9634	5498	5748	600 0691	624 0607	2
60	9536	3726	509 1591	531 3364	9288	9625	4648	4650	1
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	65°	64°	63°	62°	61°	60°	59°	58°	

	32°	33°	34°	35°	36°	37°	38°	39°	
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2	4125	545 1269	6751	574 0529	2558	2795	616 1198	7724	58
3	6591	3707	9162	2911	4910	5117	3489	9983	57
4	9057	6145	560 1572	5292	7262	7439	5780	630 2242	56
5	531 1521	8583	3981	7672	9613	9760	8069	4500	55
6	3986	546 1020	6390	575 0053	589 1964	603 2080	617 0359	6758	54
7	6450	3456	8798	2432	4314	4400	2648	9015	53
8	8913	5892	561 1206	4811	6663	6719	4936	631 1272	52
9	532 1376	8328	3614	7190	9012	9038	7224	3528	51
10	3839	547 0763	6021	9568	590 1361	604 1356	9511	5784	50
11	6301	3198	8428	576 1946	3709	3674	618 1798	8039	49
12	8763	5632	562 0834	4323	6057	5991	4084	632 0293	48
13	533 1224	8066	3239	6700	8404	8308	6370	2547	47
14	3685	548 0499	5645	9076	591 0750	605 0624	8655	4800	46
15	6145	2932	8049	577 1452	3096	2940	619 0939	7053	45
16	8605	5365	563 0453	3827	5442	5255	3224	9306	44
17	534 1065	7797	2857	6202	7787	7570	5507	633 1557	43
18	3523	549 0228	5260	8576	592 0132	9884	7790	3809	42
19	5982	2659	7663	578 0950	2476	606 2196	620 0073	6059	41
20	8440	5090	564 0066	3323	4819	4511	2355	8310	40
21	535 0896	7520	2467	5696	7163	6824	4636	634 0559	39
22	3355	9950	4369	8069	9505	9136	6917	2808	38
23	5812	550 2379	7270	579 0440	593 1847	607 1447	9198	5057	37
24	8268	4807	9670	2812	4189	3758	621 1478	7305	36
25	536 0724	7236	565 2070	5183	6530	6069	3757	9553	35
26	3179	9663	4469	7553	8871	8379	6036	635 1800	34
27	5634	551 2091	6868	9923	594 1211	608 0689	8314	4046	33
28	8089	4518	9267	580 2292	3550	2998	622 0592	6292	32
29	537 0543	6944	566 1665	4661	5889	5306	2870	8537	31
30	2996	9370	4062	7030	8228	7614	5146	636 0782	30
31	5449	552 1795	6459	9397	595 0566	9922	7423	3026	29
32	7902	4220	8856	581 1765	2904	609 2229	9698	5270	28
33	538 0354	6645	567 1252	4132	5241	4535	623 1974	7513	27
34	2806	9069	3648	6498	7577	6841	4248	9756	26
35	5257	553 1492	6043	8864	9913	9147	6522	637 1998	25
36	7708	3915	8437	582 1230	596 2249	610 1452	8796	4240	24
37	539 0158	6338	568 0832	3595	4584	3756	624 1069	3481	23
38	2608	8760	3225	5959	6918	6060	3342	8721	22
39	5058	554 1182	5619	8323	9252	8363	5614	638 0961	21
40	7507	3603	8011	583 0687	597 1586	611 0666	7885	3201	20
41	9955	6024	569 0403	3050	3919	2969	625 0156	5440	19
42	540 2403	8444	2795	5412	6251	5270	2427	7678	18
43	4851	555 0864	5187	7774	8583	7572	4696	9916	17
44	7298	3283	7577	584 0136	598 0915	9873	6966	639 2153	16
45	9745	5702	9968	2497	3246	612 2173	9235	4390	15
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47	4637	556 0539	4747	7217	7906	6772	3771	8862	13
48	7082	2956	7136	9577	599 0236	9071	6038	640 1097	12
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55	4187	9865	3844	6080	6528	5147	628 1894	6728	5
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57	9069	4692	8614	587 0790	601 1179	9736	6420	642 1189	3
58	544 1510	7105	573 0998	3145	3503	615 2029	8682	3418	2
59	3951	9517	3381	5499	5827	4322	629 0943	5647	1
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	57°	56°	55°	54°	53°	52°	51°	50°	

	32°	33°	34°	35°	36°	37°	38°	39°	
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2	6786	650 2350	675 3553	701 0749	727 4318	4666	782 2229	7478	58
3	626 0834	6490	7790	5089	8767	9232	6919	811 2300	57
4	4884	651 0631	676 2028	9430	728 3218	755 3799	783 1611	7124	56
5	8935	4774	6268	702 3773	7671	8369	6305	812 1951	55
6	627 2988	8918	677 0509	8118	729 2125	756 2941	784 1002	6780	54
7	7042	652 3064	4752	703 2464	6582	7514	5700	813 1611	53
8	628 1098	7211	8997	6813	730 1041	757 2090	785 0400	6444	52
9	5155	653 1360	678 3243	704 1163	5501	6668	5103	814 1280	51
10	9214	5511	7492	5515	9963	758 1248	9808	6118	50
11	629 3274	9663	579 1741	9869	731 4428	5829	786 4515	815 0958	49
12	7336	654 3817	5993	705 4224	8894	759 0413	9224	5801	48
13	630 1399	7972	680 0246	8581	732 3362	4999	787 3935	816 0646	47
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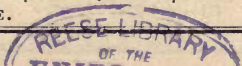
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13	90941	91927	09475	44903	99669	75386	73847	97049	47
14	97495	98747	16581	52320	12907421	83502	82358	14405991	46
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22	50081	53472	73615	11848	69649	48658	50698	77798	38
23	56674	60334	80767	19313	77454	56832	59272	86808	37
24	63271	67200	87924	26784	85265	65011	67852	95825	36
25	69872	74071	95035	34260	93081	73198	76440	14504850	35
26	76478	80947	12102252	41742	13000904	81390	85034	13883	34
27	83088	87827	09424	49229	08733	89589	93636	22923	33
28	89702	94712	16601	56721	16567	97794	14002245	31971	32
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31	09571	15395	38162	79232	40106	22449	28113	59161	29
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33	22839	29207	52562	94267	55828	38918	45393	77326	27
34	29479	36120	59769	12601792	63699	47162	54044	86420	26
35	36124	43038	66982	09323	71575	55413	62702	95522	25
36	42773	49960	74199	16860	79457	63670	71367	14604632	24
37	49427	56888	81422	24402	87345	71934	80039	13749	23
38	56085	63820	88650	31950	95239	80204	88718	22874	22
39	62747	70756	95883	39503	13103140	88481	97405	32007	21
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42	82761	91595	17613	62196	26876	13350	23506	59455	18
43	89441	98551	24866	69772	34801	21653	32221	68616	17
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3	5252	839 1455	5102	6164	4614	875 0425	3569	4624	57
4	6877	3037	6641	7660	6066	1832	4933	5342	56
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6	830 0123	6199	9717	858 0649	8967	4645	7656	7975	54
7	1745	7778	849 1254	2143	867 0417	6051	9017	9291	53
8	3366	9357	2790	3635	1866	7455	884 0377	892 0606	52
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25	833 0822	6091	8793	8901	6386	878 1222	3383	2844	35
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33	3672	8600	853 0958	862 0717	7851	2332	4134	3234	27
34	5275	844 0161	2475	2191	9281	3717	5475	4529	26
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40	4878	9508	1564	863 1019	7844	2014	3503	2285	20
41	6476	845 1064	3077	2488	9269	3394	4838	3575	19
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46	4456	8830	855 0627	9820	6381	881 0284	1503	897 0014	14
47	6050	846 0381	2135	864 1284	7801	1660	2834	1299	13
48	7643	1932	3643	2748	9221	3035	4164	2584	12
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51	2418	6579	8160	7134	3475	7155	8149	6433	9
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54	7187	847 1219	2671	1514	7722	882 1269	2128	898 0276	6
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57	1950	5853	7175	5887	1963	5376	6100	4112	3
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59	5121	8939	857 0174	8799	4786	8110	8744	6665	1
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4	62884	37946	44858	86744	67144	90086	60172	82688	56
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6	81570	57647	65672	16708782	90533	14969	86713	19711077	54
7	90925	67510	76094	19818	17402245	27430	18900006	25296	53
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13	47225	26880	38829	86256	72768	18202473	80068	19810952	47
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25	60713	46590	65368	20308	15112	53999	41795	84056	35
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5	4307	9215	1361	921 0722	7277	934 1007	1891	9911	55
6	5578	907 0440	2540	1854	8363	2045	2881	946 0854	54
7	6848	1665	3718	2986	9447	3082	3871	1795	53
8	8117	2888	4895	4116	928 0531	4119	4860	2736	52
9	9386	4111	6072	5246	1614	5154	5848	3677	51
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6	94187	43156	66283	73316	75781	87411	2-7624695	2-9207610	54
7	2-0609442	59575	84016	92540	96706	2-6210286	49822	35358	53
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25	87200	58691	2-2907257	43168	78598	28085	2-8109164	43016	35
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39	2-1107470	96112	64076	22041	82686	61181	75831	48926	21
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2	2361	4747	4219	0762	4363	5008	2684	7380	58
3	3258	5595	5019	1513	5065	5660	3287	7933	57
4	4154	6443	5818	2263	5766	6311	3889	8485	56
5	5050	7290	6616	3012	6466	6962	4490	9037	55
6	5944	8136	7413	3761	7165	7612	5090	9587	54
7	6838	8981	8210	4508	7863	8261	5689	982 0137	53
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9	8623	957 0669	9800	6001	9258	9556	6886	1234	51
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37	3273	3961	1726	6555	9432	7347	3296	6239	23
38	4141	4781	2497	7277	9105	7970	3860	6763	22
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3	68468	3-2810907	89356	51207	57440	87866	4-7249012	57
4	99122	45164	3-5027916	94963	4-0307550	4-3545861	4-7316954	56
5	3-0929831	79487	66555	3-7538815	57779	4-3604003	85083	55
6	60596	3-2913876	3-5105273	82763	4-0408125	62293	4-7453401	54
7	91416	48330	44070	3-7626807	58590	4-3720731	4-7521907	53
8	3-1022291	82851	82946	70947	4-0509174	79317	90603	52
9	53223	3-3017438	3-5221902	3-7715185	59877	4-3838054	4-7659490	51
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	80°	81°	82°	83°	84°	85°	86°	87°	
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2	9849 086	792	489	9926 169	825	452	9976 045	598	58
3	589	9878 245	891	521	9946 127	704	245	748	57
4	9850 091	697	9904 293	873	428	954	445	898	56
5	593	9879 148	694	9927 224	729	9963 204	645	9987 046	55
6	9351 093	599	9905 095	573	9947 028	453	843	194	54
7	593	9880 048	494	922	327	701	9977 040	340	53
8	9852 092	497	893	9928 271	625	948	237	486	52
9	590	945	9906 290	618	921	9964 195	433	631	51
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13	574	728	873	999	9949 101	9965 172	207	203	47
14	9855 068	9883 172	9908 266	9930 342	393	414	399	344	46
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17	544	498	442	367	9950 266	9966 135	968	761	43
18	9857 035	939	832	706	556	374	9973 156	899	42
19	524	9885 378	9910 221	9932 045	844	612	343	9989 035	41
20	9858 013	817	610	384	9951 132	849	530	171	40
21	501	9886 255	997	721	419	9967 085	716	306	39
22	988	692	9911 384	9933 057	705	321	900	440	38
23	9859 475	9887 128	770	393	990	555	9980 084	573	37
24	960	564	9912 155	728	9952 274	789	267	706	36
25	9860 445	998	540	9934 062	557	9968 022	450	837	35
26	929	9888 432	923	395	840	254	631	968	34
27	9861 412	865	9913 306	727	9953 122	485	811	9990 098	33
28	894	9889 297	688	9935 058	403	715	991	227	32
29	9862 375	728	9914 069	389	683	945	9981 170	355	31
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31	9863 336	588	828	9936 047	9954 240	401	525	609	29
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34	770	872	961	9937 029	9955 070	9970 080	9982 052	983	26
35	9865 246	9892 298	9916 337	355	345	304	225	9991 106	25
36	722	723	712	679	620	528	398	228	24
37	9866 196	9893 148	9917 086	9938 003	893	750	570	350	23
38	670	572	459	326	9956 165	972	742	470	22
39	9867 143	994	832	648	437	9971 193	912	590	21
40	615	9894 416	9918 204	969	708	413	9983 082	709	20
41	9868 087	838	574	9939 290	978	633	250	827	19
42	557	9895 258	944	610	9957 247	851	418	944	18
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45	964	514	9920 049	563	9958 049	502	917	290	15
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47	897	9897 347	782	9941 195	580	931	245	517	13
48	9871 363	762	9921 147	510	844	9973 145	408	629	12
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55	598	646	679	688	669	615	524	390	5
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57	514	462	394	9944 303	9961 183	9975 023	835	600	3
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59	9876 428	9902 275	9925 107	914	693	437	9986 143	806	1
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3	686311	5-7003663	496092	607056	8-2035239	949022	546093	57
4	767051	101256	616502	759437	234384	9-6220486	585294	56
5	848035	199173	737359	912456	434485	493475	624761	55
6	929264	297416	858665	7-2066116	635547	768000	664495	54
7	5-2010738	395988	980422	220422	837579	9-7044075	704500	53
8	092459	4-4889	6-4102633	375378	8-3040586	321713	744779	52
9	174428	594122	225301	530987	244577	600927	785333	51
10	256647	693688	348428	687255	449558	881732	826167	50
11	339116	793588	472017	844184	655536	9-8164140	867282	49
12	421836	893825	596070	7-3001780	862519	448166	908682	48
13	504809	994400	720591	160047	8-4070515	733823	950370	47
14	589035	5-8095315	845581	318989	279531	9-9021125	992349	46
15	671517	196572	971043	478610	489573	310088	12-034622	45
16	755255	298172	6-5096981	638916	700651	600724	077192	44
17	839251	400117	223396	799909	912772	893050	120062	43
18	923505	502410	350293	961595	8-5125943	10-018708	163236	42
19	5-3008018	605051	477672	7-4123978	340172	048283	206716	41
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21	177830	811386	733892	450855	771838	107954	294609	39
22	263131	915084	862739	615357	989290	138054	339028	38
23	348696	5-9019138	992080	780576	8-6207833	168332	383768	37
24	434527	123550	6-6121919	946514	427475	198789	428831	36
25	520626	228322	252258	7-5113178	648223	229428	474221	35
26	606993	333455	383100	280571	870088	260249	519942	34
27	693630	438952	514449	448699	8-7093077	291255	565997	33
28	780538	544815	646307	617567	317198	322447	612390	32
29	867718	651045	778677	787179	542461	353827	659125	31
30	955172	757644	911562	957541	768874	385397	706205	30
31	5-4042901	864614	6-7044966	7-6128657	996446	417158	753634	29
32	130906	971957	178891	300533	8-8225186	449112	801417	28
33	219188	6-0079676	313341	473174	455103	481261	849557	27
34	307750	187772	448318	646584	686206	513607	898058	26
35	396592	296247	583826	820769	918505	546151	946924	25
36	485715	405103	719867	995735	8-9152009	578895	996160	24
37	575121	514343	856446	7-7171486	386726	611841	13-045769	23
38	664812	623967	993565	348028	622668	644992	095757	22
39	754788	733979	6-8131227	525366	859843	678348	146127	21
40	845052	844381	269437	703506	9-0098261	711913	196883	20
41	935604	955174	408196	882453	337933	745687	248031	19
42	5-5026446	6-1066360	547508	7-8062212	578867	779673	299574	18
43	117579	177943	687378	242790	821074	813872	351518	17
44	209005	289923	827807	424191	9-1064564	848288	403867	16
45	300724	402303	968799	606423	309348	882921	456625	15
46	392740	515085	6-9110359	789489	555436	917775	599798	14
47	485052	628272	252489	973396	802838	952850	663391	13
48	577663	741865	395192	7-9158151	9-2051564	988150	617409	12
49	670574	855867	538473	343758	301627	11-023676	671856	11
50	763786	970279	682335	530224	553035	059431	726738	10
51	857302	6-2085106	826781	717555	805802	095416	782060	9
52	951121	200347	971806	905756	9-3059936	131635	837827	8
53	5-6045247	316007	7-0117441	8-0094835	315450	168C89	894C45	7
54	139680	432086	263662	284796	572355	204780	950719	6
55	234421	548588	410482	475647	830663	241712	14-007856	5
56	329474	665515	557905	667394	9-4090384	278985	065459	4
57	424838	782868	705934	860042	351531	316304	123536	3
58	520516	900651	854573	8-1053599	614116	353970	182092	2
59	616509	6-3018866	7-1003826	248071	878149	391885	241134	1
60	712818	137515	153697	443464	9-5143645	430052	300C66	0
	10°	9°	8°	7°	6°	5°	4°	

NAT. SINE.

NAT. TAN.

	88°	89°			86°	87°	88°	89°	
0	9993 908	9998 477 60			0 14 300666	19-081137	28-636253	57-289962	60
1	9994 009	527 59			1 360696	187930	877089	58-261174	59
2	110	577 58			2 421230	295922	29-122005	59-265872	58
3	209	625 57			3 482273	405133	371106	60-305820	57
4	308	673 56			4 543833	515584	624499	61-382905	56
5	405	720 55			5 605916	627296	882299	62-499154	55
6	502	766 54			6 668529	740291	30-144619	63-656741	54
7	598	812 53			7 731679	854591	411580	64-858008	53
8	693	856 52			8 795372	970219	683307	66-105473	52
9	788	900 51			9 859616	20-087199	959928	67-401854	51
10	881	942 50			10 924417	205553	31-241577	68-750087	50
11	974	984 49			11 989784	325308	528392	70-153346	49
12	9995 066	9999 025 48			12 1055723	446486	820516	71-615070	48
13	157	065 47			13 122242	569115	32-118099	73-138991	47
14	247	105 46			14 189349	693220	421295	74-729165	46
15	336	143 45			15 257052	818828	730264	76-390009	45
16	424	181 44			16 325358	945966	33-045173	78-126342	44
17	512	218 43			17 394276	21-074664	366194	79-943430	43
18	599	254 42			18 463814	204949	693509	81-847041	42
19	684	289 41			19 533981	336851	34-027303	83-843507	41
20	770	323 40			20 604784	470401	367771	85-939791	40
21	854	357 39			21 676233	605630	715115	88-143572	39
22	937	389 38			22 748337	742569	35-069546	90-463336	38
23	9996 020	421 37			23 821105	881251	431282	92-908487	37
24	101	452 36			24 894545	22-021710	800553	95-489475	36
25	182	482 35			25 963667	163980	36-177596	98-217943	35
26	262	511 34			26 16-043482	308097	562659	101-10690	34
27	341	539 33			27 118998	454096	956001	104-17094	33
28	419	567 32			28 195225	602015	37-357892	107-42648	32
29	497	595 31			29 272174	751892	768613	110-89205	31
30	573	619 30			30 349855	903766	38-188459	114-58865	30
31	649	644 29			31 428279	23-057677	617738	118-54018	29
32	724	668 28			32 507456	213666	39-056771	122-77396	28
33	798	602 27			33 587396	371777	505895	127-32134	27
34	871	714 26			34 668112	532052	965460	132-21851	26
35	943	736 25			35 749614	694537	40-435837	137-50745	25
36	9997 015	756 24			36 831915	859277	917412	143-23712	24
37	086	776 23			37 915025	24-026320	41-410588	149-46502	23
38	156	795 22			38 998957	195714	915790	156-25908	22
39	224	813 21			39 17-083724	367509	42-433464	163-70019	21
40	292	831 20			40 169337	541758	964077	171-88540	20
41	360	847 19			41 255809	719512	43-508122	180-93220	19
42	426	863 18			42 343155	897826	44-066113	190-98419	18
43	492	878 17			43 431385	25-079757	638596	202-21875	17
44	556	892 16			44 520516	264361	45-226141	214-85762	16
45	620	905 15			45 610559	451700	829351	229-18166	15
46	683	917 14			46 701529	641832	46-448862	245-55198	14
47	745	929 13			47 793442	834823	47-085343	264-44080	13
48	807	939 12			48 886310	26-030736	739501	286-47773	12
49	867	949 11			49 980150	229638	48-412084	312-52137	11
50	927	958 10			50 19-074977	431600	49-103881	343-77371	10
51	986	966 9			51 170807	636690	815726	381-97099	9
52	9998 044	973 8			52 267654	844984	50-548506	429-71757	8
53	101	979 7			53 365537	27-056557	51-303157	491-10000	7
54	157	985 6			54 464471	271486	52-080673	572-95721	6
55	213	989 5			55 564473	489853	892109	687-54687	5
56	267	993 4			56 665562	711740	53-708587	859-43630	4
57	321	996 3			57 767754	937233	54-561300	1145-9153	3
58	374	999 2			58 871068	28-166422	55-441517	1718-8732	2
59	426	1-0000 000 1			59 975523	399397	56-350590	3437-7467	1
60	477	000 0			60 19-081137	636253	57-289962	Infinite.	0
	1°	0°				3°	2°	1°	0°

NAT. COSINE.

NAT. COTAN.

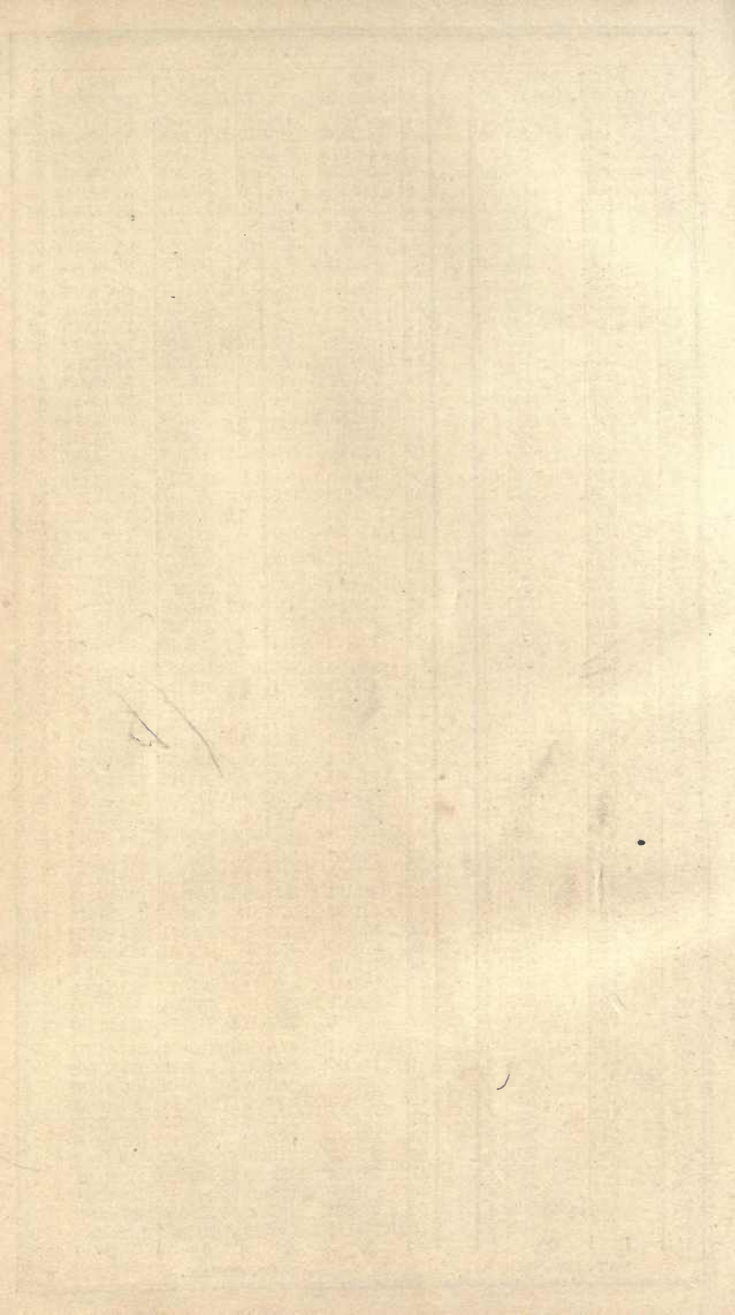


TABLE OF RADII, &c.—Chord 100 Feet.

Angle of Deflex'n.	Radius in feet.	Def. dist. in feet.	Angle of Deflex'n.	Radius in feet.	Def. dist. in feet.	Angle of Deflex'n.	Radius in feet.	Def. dist. in feet.
° /			° /			° /		
5	68760.0	.145	3 25	1677.0	5.962	12 15	468.7	21.360
10	34380.0	.291	30	1637.0	6.108	30	459.3	21.790
15	22920.0	.436	35	1599.0	6.253	45	450.3	22.210
20	17190.0	.581	40	1563.0	6.398	13 45	441.7	22.640
25	13752.0	.727	45	1528.0	6.544	15	433.4	23.070
30	11460.0	.872	50	1495.0	6.689	30	425.5	23.510
35	9823.0	1.017	55	1463.0	6.835	45	417.7	23.940
40	8595.0	1.163	4 15	1433.0	6.980	14 15	410.3	24.370
45	7640.0	1.308	30	1348.0	7.416	30	403.1	24.810
50	6876.0	1.453	45	1274.0	7.853	45	396.2	25.240
55	6251.0	1.600	5 45	1207.0	8.289	15 45	389.6	25.670
1 5	5730.0	1.745	15	1146.0	8.722	15 15	383.1	26.110
10	5289.0	1.890	30	1092.0	9.159	15 30	376.9	26.520
15	4912.0	2.036	45	1042.0	9.595	30 45	370.8	26.940
20	4584.0	2.181	6 15	996.8	10.030	45 30	365.0	27.370
25	4298.0	2.327	30	955.4	10.470	16 30	359.3	27.830
30	4045.0	2.472	45	917.0	10.900	30 45	348.4	28.700
35	3820.0	2.618	6 30	882.0	11.340	17 30	338.3	29.560
40	3619.0	2.763	7 15	849.3	11.780	30 45	328.7	30.430
45	3438.0	2.908	7 30	819.0	12.210	18 30	319.6	31.290
50	3274.0	3.054	15	790.8	12.640	30 45	311.0	32.500
55	3125.0	3.199	30	764.5	13.080	19 30	302.9	33.010
2 55	2990.0	3.345	45	739.9	13.510	30 45	295.3	33.870
10	2865.0	3.490	8 15	716.8	13.950	20 30	287.9	34.730
15	2750.0	3.635	30	695.1	14.380	21 45	274.4	36.440
20	2644.0	3.781	45	674.6	14.810	22 30	262.0	38.150
25	2547.0	3.926	6 45	655.5	15.250	23 45	250.8	39.870
30	2456.0	4.072	9 15	637.3	15.680	24 30	240.5	41.580
35	2371.0	4.217	30	620.2	16.120	25 45	231.0	43.280
40	2292.0	4.363	45	603.8	16.550	26 30	222.3	44.980
45	2218.0	4.508	10 45	588.4	16.990	27 45	214.2	46.680
50	2149.0	4.653	11 30	573.7	17.430	28 30	206.7	48.380
55	2084.0	4.799	15 45	559.7	17.870	29 45	199.7	50.070
3 55	2023.0	4.944	30 30	546.4	18.300	30 30	193.2	51.760
10	1965.0	5.090	45 45	533.8	18.730	31 45	187.1	53.450
15	1910.0	5.235	11 15	521.7	19.170	32 30	181.4	55.130
20	1859.0	5.380	15 30	510.1	19.610	33 45	176.0	56.800
25	1810.0	5.526	30 45	499.1	20.050	34 30	171.0	58.470
30	1763.0	5.671	45 30	488.5	20.500	35 45	166.3	60.140
35	1719.0	5.817	12 45	478.3	20.940	36 30	161.8	61.800

TABLE OF LONG CHORDS.

Radii in feet.	Angle of Deflection.	Length of Chord in feet required to subtend			
		1 Station.	2 Stations.	3 Stations.	4 Stations.
5730.0	1°	100	200.0	300.0	400.0
4584.0	$\frac{1}{4}$	100	200.0	300.0	399.9
3820.0	$\frac{1}{2}$	100	200.0	300.0	399.9
3274.0	$\frac{3}{4}$	100	200.0	300.0	399.8
2865.0	2°	100	200.0	299.9	399.7
2547.0	$\frac{1}{4}$	100	200.0	299.9	399.6
2292.0	$\frac{1}{2}$	100	200.0	299.8	399.5
2084.0	$\frac{3}{4}$	100	200.0	299.8	399.4
1910.0	3°	100	200.0	299.7	399.3
1763.0	$\frac{1}{4}$	100	200.0	299.7	399.2
1637.0	$\frac{1}{2}$	100	200.0	299.6	399.1
1528.0	$\frac{3}{4}$	100	200.0	299.6	399.0
1433.0	4°	100	199.9	299.6	398.9
1348.0	$\frac{1}{4}$	100	199.9	299.5	398.7
1274.0	$\frac{1}{2}$	100	199.9	299.4	398.5
1207.0	$\frac{3}{4}$	100	199.9	299.3	398.3
1146.0	5°	100	199.9	299.2	398.0
1092.0	$\frac{1}{4}$	100	199.8	299.1	397.8
1042.0	$\frac{1}{2}$	100	199.8	299.0	397.6
996.8	$\frac{3}{4}$	100	199.7	298.9	397.5
955.4	6°	100	199.7	298.8	397.3
917.0	$\frac{1}{4}$	100	199.7	298.7	397.0
882.0	$\frac{1}{2}$	100	199.7	298.6	396.7
849.3	$\frac{3}{4}$	100	199.6	298.5	396.5
819.0	7°	100	199.6	298.4	396.2
790.8	$\frac{1}{4}$	100	199.6	298.3	396.0
764.5	$\frac{1}{2}$	100	199.6	298.2	395.7
739.9	$\frac{3}{4}$	100	199.6	298.1	395.4
716.8	8°	100	199.6	298.0	395.1
695.1	$\frac{1}{4}$	100	199.5	297.9	394.8
674.6	$\frac{1}{2}$	100	199.5	297.8	394.5
655.5	$\frac{3}{4}$	100	199.4	297.7	394.3
637.3	9°	100	199.4	297.5	394.1
620.2	$\frac{1}{4}$	100	199.4	297.4	393.7
603.8	$\frac{1}{2}$	100	199.3	297.3	393.2
588.4	$\frac{3}{4}$	100	199.2	297.2	392.8
573.7	10°	100	199.2	297.0	392.4

TABLE OF ORDINATES.

Ordinates 10 feet apart.—Chord 100 feet.

Deflexion Angle in Degrees and Minutes.		Distances of the Ordinates from the end of the 100 feet Chord.				
		50 feet.	40 feet.	30 feet.	20 feet.	10 feet.
		Lengths of Ordinates in feet.				
1	° /					
	5	·018	·017	·015	·012	·006
	10	·036	·035	·031	·023	·013
	15	·054	·052	·046	·035	·019
	20	·073	·070	·061	·047	·026
	25	·091	·087	·076	·058	·032
	30	·109	·105	·092	·070	·039
	35	·127	·123	·108	·082	·045
	40	·145	·140	·123	·093	·052
	45	·163	·157	·137	·105	·058
	50	·182	·175	·153	·117	·065
2	55	·200	·192	·168	·128	·071
		·218	·209	·183	·140	·078
	5	·236	·226	·198	·152	·085
	10	·254	·244	·214	·163	·091
	15	·273	·261	·229	·175	·098
	20	·291	·279	·244	·187	·104
	25	·309	·296	·259	·198	·111
	30	·327	·314	·275	·210	·117
	35	·345	·331	·290	·221	·124
	40	·364	·349	·305	·233	·130
	45	·382	·366	·321	·245	·137
3	50	·400	·384	·336	·256	·144
	55	·418	·401	·351	·268	·150
		·436	·419	·366	·280	·157
	5	·454	·436	·382	·291	·163
	10	·473	·454	·397	·303	·170
	15	·491	·471	·412	·315	·176
	20	·509	·489	·428	·326	·183
	25	·527	·506	·443	·338	·190
	30	·545	·524	·458	·350	·196
	35	·564	·541	·474	·361	·203
	40	·582	·559	·489	·373	·209
	45	·600	·576	·504	·384	·216
	50	·618	·594	·519	·396	·222
	55	·636	·611	·535	·408	·229
		·654	·629	·550	·419	·235
	5	·673	·646	·565	·431	·242
	10	·691	·664	·581	·443	·249
	15	·709	·681	·596	·454	·255
	20	·727	·699	·611	·466	·262
25	·745	·716	·627	·478	·268	

TABLE OF ORDINATES.—CONTINUED.

Ordinates 10 feet apart.—Chord 100 feet.

Deflexion Angle in Degrees and Minutes.	Distances of the Ordinates from the end of the 100 feet Chord.				
	50 feet.	40 feet.	30 feet.	20 feet.	10 feet.
	Lengths of Ordinates in feet.				
° 3					
30	·764	·734	·642	·489	·275
35	·782	·751	·657	·501	·281
40	·800	·769	·673	·512	·288
45	·818	·786	·688	·524	·294
50	·836	·804	·703	·536	·301
55	·854	·821	·718	·547	·308
° 4					
873	·873	·839	·734	·559	·314
15	·927	·891	·780	·594	·334
30	·981	·944	·825	·629	·354
45	1·036	·996	·871	·664	·373
° 5					
1·091	1·091	1·048	·917	·699	·393
15	1·146	1·100	·963	·734	·413
30	1·200	1·153	1·009	·769	·432
45	1·255	1·205	1·055	·804	·452
° 6					
1·309	1·309	1·258	1·100	·839	·472
15	1·364	1·310	1·146	·874	·492
30	1·419	1·362	1·192	·909	·511
45	1·473	1·415	1·238	·944	·531
° 7					
1·528	1·528	1·467	1·284	·979	·551
15	1·582	1·520	1·330	1·014	·570
30	1·637	1·572	1·375	1·048	·590
45	1·692	1·624	1·421	1·083	·610
° 8					
1·746	1·746	1·677	1·467	1·118	·629
15	1·801	1·729	1·513	1·153	·649
30	1·855	1·782	1·559	1·188	·669
45	1·910	1·834	1·605	1·223	·689
° 9					
1·965	1·965	1·886	1·651	1·258	·708
15	2·019	1·939	1·696	1·293	·728
30	2·074	1·991	1·742	1·328	·748
45	2·128	2·044	1·788	1·363	·767
° 10					
2·183	2·183	2·096	1·834	1·398	·787
15	2·238	2·148	1·880	1·433	·807
30	2·292	2·201	1·926	1·468	·827
45	2·347	2·254	1·972	1·503	·846
° 11					
2·401	2·401	2·306	2·018	1·538	·866
15	2·456	2·359	2·064	1·574	·886
30	2·511	2·411	2·110	1·609	·906
45	2·566	2·464	2·156	1·644	·926
° 12					
2·620	2·620	2·516	2·203	1·680	·946
15	2·675	2·569	2·249	1·715	·966
30	2·730	2·621	2·295	1·750	·985

TABLE OF ORDINATES.—CONTINUED.

Ordinates 10 feet apart.—Chord 100 feet.

Deflexion Angle in Degrees and Minutes.		Distances of the Ordinates from the end of the 100 feet Chord.				
		50 feet.	40 feet.	30 feet.	20 feet.	10 feet.
		Lengths of Ordinates in feet.				
°	'					
12	45	2·785	2·674	2·341	1·785	1·005
13		2·839	2·726	2·387	1·820	1·025
	15	2·894	2·779	2·433	1·855	1·045
	30	2·949	2·832	2·479	1·891	1·065
	45	3·000	2·884	2·525	1·926	1·085
14		3·058	2·937	2·571	1·961	1·105
	15	3·113	2·989	2·618	1·996	1·124
	30	3·168	3·042	2·664	2·031	1·144
	45	3·222	3·094	2·710	2·067	1·164
15		3·277	3·147	2·756	2·102	1·184
	15	3·332	3·200	2·802	2·137	1·204
	30	3·387	3·252	2·848	2·172	1·224
	45	3·442	3·305	2·895	2·208	1·244
16		3·496	3·358	2·941	2·243	1·264
	30	3·606	3·463	3·033	2·314	1·304
17		3·716	3·569	3·125	2·384	1·344
	30	3·826	3·674	3·218	2·455	1·384
18		3·935	3·779	3·310	2·525	1·424
	30	4·045	3·885	3·403	2·596	1·464
19		4·155	3·990	3·495	2·666	1·504
	30	4·265	4·096	3·588	2·737	1·544
20		4·375	4·201	3·680	2·808	1·583

A TABLE OF THE SQUARES AND SQUARE ROOTS OF NUMBERS.

From 1 to 1000.

No.	Squares.	Square Roots.	No.	Squares.	Square Roots.
1	1	1·0000	44	1936	6·6332
2	4	1·4142	45	2025	6·7082
3	9	1·7320	46	2116	6·7823
4	16	2·0000	47	2209	6·8556
5	25	2·2360	48	2304	6·9282
6	36	2·4495	49	2401	7·0000
7	49	2·6457	50	2500	7·0711
8	64	2·8284	51	2601	7·1414
9	81	3·0000	52	2704	7·2111
10	100	3·1623	53	2809	7·2801
11	121	3·3166	54	2916	7·3485
12	144	3·4641	55	3025	7·4162
13	169	3·6055	56	3136	7·4833
14	196	3·7416	57	3249	7·5498
15	225	3·8730	58	3364	7·6158
16	256	4·0000	59	3481	7·6811
17	289	4·1231	60	3600	7·7460
18	324	4·2426	61	3721	7·8102
19	361	4·3589	62	3844	7·8740
20	400	4·4721	63	3969	7·9372
21	441	4·5826	64	4096	8·0000
22	484	4·6904	65	4225	8·0623
23	529	4·7958	66	4356	8·1240
24	576	4·8990	67	4489	8·1853
25	625	5·0000	68	4624	8·2462
26	676	5·0990	69	4761	8·3066
27	729	5·1961	70	4900	8·3666
28	784	5·2915	71	5041	8·4261
29	841	5·3852	72	5184	8·4853
30	900	5·4772	73	5329	8·5440
31	961	5·5678	74	5476	8·6023
32	1024	5·6568	75	5625	8·6603
33	1089	5·7446	76	5776	8·7178
34	1156	5·8309	77	5929	8·7750
35	1225	5·9161	78	6084	8·8318
36	1296	6·0000	79	6241	8·8882
37	1369	6·0828	80	6400	8·9443
38	1444	6·1644	81	6561	9·0000
39	1521	6·2450	82	6724	9·0554
40	1600	6·3246	83	6889	9·1104
41	1681	6·4031	84	7056	9·1651
42	1764	6·4807	85	7225	9·2195
43	1849	6·5574	86	7396	9·2736

A TABLE OF THE SQUARES AND SQUARE ROOTS OF NUMBERS.—CONTINUED.

From 1 to 1000.

No.	Squares.	Square Roots.	No.	Squares.	Square Roots.
87	7569	9.3274	130	16900	11.4017
88	7744	9.3808	131	17161	11.4455
89	7921	9.4340	132	17424	11.4891
90	8100	9.4868	133	17689	11.5326
91	8281	9.5394	134	17956	11.5758
92	8464	9.5917	135	18225	11.6189
93	8649	9.6436	136	18496	11.6619
94	8836	9.6954	137	18769	11.7047
95	9025	9.7468	138	19044	11.7473
96	9216	9.7979	139	19321	11.7898
97	9409	9.8488	140	19600	11.8322
98	9604	9.8995	141	19881	11.8743
99	9801	9.9499	142	20164	11.9164
100	10000	10.0000	143	20449	11.9583
101	10201	10.0499	144	20736	12.0000
102	10404	10.0995	145	21025	12.0416
103	10609	10.1489	146	21316	12.0830
104	10816	10.1980	147	21609	12.1244
105	11025	10.2469	148	21904	12.1655
106	11236	10.2956	149	22201	12.2065
107	11449	10.3440	150	22500	12.2474
108	11664	10.3923	151	22801	12.2882
109	11881	10.4403	152	23104	12.3288
110	12100	10.4881	153	23409	12.3693
111	12321	10.5356	154	23716	12.4097
112	12544	10.5830	155	24025	12.4499
113	12769	10.6301	156	24336	12.4900
114	12996	10.6771	157	24649	12.5300
115	13225	10.7238	158	24964	12.5700
116	13456	10.7703	159	25281	12.6095
117	13689	10.8166	160	25600	12.6491
118	13924	10.8628	161	25921	12.6886
119	14161	10.9087	162	26244	12.7279
120	14400	10.9544	163	26569	12.7671
121	14641	11.0000	164	26896	12.8062
122	14884	11.0454	165	27225	12.8452
123	15129	11.0905	166	27556	12.8841
124	15376	11.1355	167	27889	12.9228
125	15625	11.1803	168	28224	12.9615
126	15876	11.2250	169	28561	13.0000
127	16129	11.2694	170	28900	13.0384
128	16384	11.3137	171	29241	13.0767
129	16641	11.3578	172	29584	13.1149

A TABLE OF THE SQUARES AND SQUARE ROOTS OF NUMBERS.—CONTINUED.

From 1 to 1000.

No.	Squares.	Square Roots.	No.	Squares.	Square Roots.
173	29929	13·1529	216	46656	14·6969
174	30276	13·1909	217	47089	14·7309
175	30625	13·2287	218	47524	14·7648
176	30976	13·2665	219	47961	14·7986
177	31329	13·3041	220	48400	14·8324
178	31684	13·3417	221	48841	14·8661
179	32041	13·3791	222	49284	14·8997
180	32400	13·4164	223	49729	14·9332
181	32761	13·4536	224	50176	14·9666
182	33124	13·4907	225	50625	15·0000
183	33489	13·5277	226	51076	15·0333
184	33856	13·5647	227	51529	15·0665
185	34225	13·6015	228	51984	15·0997
186	34596	13·6382	229	52441	15·1327
187	34969	13·6748	230	52900	15·1657
188	35344	13·7113	231	53361	15·1987
189	35721	13·7477	232	53824	15·2315
190	36100	13·7840	233	54289	15·2643
191	36481	13·8203	234	54756	15·2970
192	36864	13·8564	235	55225	15·3297
193	37249	13·8924	236	55696	15·3623
194	37636	13·9284	237	56169	15·3948
195	38025	13·9642	238	56644	15·4272
196	38416	14·0000	239	57121	15·4596
197	38809	14·0357	240	57600	15·4919
198	39204	14·0712	241	58081	15·5242
199	39601	14·1067	242	58564	15·5563
200	40000	14·1421	243	59049	15·5885
201	40401	14·1774	244	59536	15·6205
202	40804	14·2127	245	60025	15·6525
203	41209	14·2478	246	60516	15·6844
204	41616	14·2828	247	61009	15·7162
205	42025	14·3178	248	61504	15·7480
206	42436	14·3527	249	62001	15·7797
207	42849	14·3874	250	62500	15·8114
208	43264	14·4222	251	63001	15·8430
209	43681	14·4568	252	63504	15·8745
210	44100	14·4914	253	64009	15·9060
211	44521	14·5258	254	64516	15·9374
212	44944	14·5602	255	65025	15·9687
213	45369	14·5945	256	65536	16·0000
214	45796	14·6287	257	66049	16·0312
215	46225	14·6629	258	66564	16·0624

A TABLE OF THE SQUARES AND SQUARE ROOTS OF NUMBERS.—CONTINUED.

From 1 to 1000.

No.	Squares.	Square Roots.	No.	Squares.	Square Roots.
259	67081	16.0935	302	91204	17.3781
260	67600	16.1245	303	91809	17.4069
261	68121	16.1555	304	92416	17.4356
262	68644	16.1864	305	93025	17.4642
263	69169	16.2173	306	93636	17.4928
264	69696	16.2481	307	94249	17.5214
265	70225	16.2788	308	94864	17.5499
266	70756	16.3095	309	95481	17.5784
267	71289	16.3401	310	96100	17.6068
268	71824	16.3707	311	96721	17.6352
269	72361	16.4012	312	97344	17.6635
270	72900	16.4317	313	97969	17.6918
271	73441	16.4621	314	98596	17.7200
272	73984	16.4924	315	99225	17.7482
273	74529	16.5227	316	99856	17.7764
274	75076	16.5529	317	100489	17.8045
275	75625	16.5831	318	101124	17.8325
276	76176	16.6132	319	101761	17.8606
277	76729	16.6433	320	102400	17.8885
278	77284	16.6733	321	103041	17.9165
279	77841	16.7033	322	103684	17.9444
280	78400	16.7332	323	104329	17.9722
281	78961	16.7630	324	104976	18.0000
282	79524	16.7928	325	105625	18.0277
283	80089	16.8226	326	106276	18.0555
284	80656	16.8523	327	106929	18.0831
285	81225	16.8819	328	107584	18.1108
286	81796	16.9115	329	108241	18.1384
287	82369	16.9411	330	108900	18.1659
288	82944	16.9706	331	109561	18.1934
289	83521	17.0000	332	110224	18.2209
290	84100	17.0294	333	110889	18.2483
291	84681	17.0587	334	111556	18.2757
292	85264	17.0880	335	112225	18.3030
293	85849	17.1172	336	112896	18.3303
294	86436	17.1464	337	113569	18.3576
295	87025	17.1756	338	114244	18.3848
296	87616	17.2046	339	114921	18.4119
297	88209	17.2337	340	115600	18.4391
298	88804	17.2627	341	116281	18.4662
299	89401	17.2916	342	116964	18.4932
300	90000	17.3205	343	117649	18.5203
301	90601	17.3493	344	118336	18.5472

A TABLE OF THE SQUARES AND SQUARE ROOTS OF NUMBERS.—CONTINUED.

From 1 to 1000.

No.	Squares.	Square Roots.	No.	Squares.	Square Roots.
345	119025	18-5742	388	150544	19-6977
346	119716	18-6011	389	151321	19-7231
347	120409	18-6279	390	152100	19-7484
348	121104	18-6548	391	152881	19-7737
349	121801	18-6815	392	153664	19-7990
350	122500	18-7083	393	154449	19-8242
351	123201	18-7350	394	155236	19-8494
352	123904	18-7617	395	156025	19-8746
353	124609	18-7883	396	156816	19-8997
354	125316	18-8149	397	157609	19-9248
355	126025	18-8414	398	158404	19-9499
356	126736	18-8680	399	159201	19-9750
357	127449	18-8944	400	160000	20-0000
358	128164	18-9209	401	160801	20-0250
359	128881	18-9473	402	161604	20-0499
360	129600	18-9737	403	162409	20-0749
361	130321	19-0000	404	163216	20-0997
362	131044	19-0263	405	164025	20-1246
363	131769	19-0526	406	164836	20-1494
364	132496	19-0788	407	165649	20-1742
365	133225	19-1050	408	166464	20-1990
366	133956	19-1311	409	167281	20-2237
367	134689	19-1572	410	168100	20-2485
368	135424	19-1833	411	168921	20-2731
369	136161	19-2094	412	169744	20-2978
370	136900	19-2354	413	170569	20-3224
371	137641	19-2614	414	171396	20-3470
372	138384	19-2873	415	172225	20-3715
373	139129	19-3132	416	173056	20-3961
374	139876	19-3391	417	173889	20-4206
375	140625	19-3649	418	174724	20-4450
376	141376	19-3907	419	175561	20-4695
377	142129	19-4165	420	176400	20-4939
378	142884	19-4422	421	177241	20-5183
379	143641	19-4679	422	178084	20-5426
380	144400	19-4936	423	178929	20-5670
381	145161	19-5192	424	179776	20-5913
382	145924	19-5448	425	180625	20-6155
383	146689	19-5704	426	181476	20-6398
384	147456	19-5959	427	182329	20-6640
385	148225	19-6214	428	183184	20-6882
386	148996	19-6469	429	184041	20-7123
387	149769	19-6723	430	184900	20-7364

A TABLE OF THE SQUARES AND SQUARE ROOTS OF NUMBERS.—CONTINUED.

From 1 to 1000.

No.	Squares.	Square Roots.	No.	Squares.	Square Roots.
431	185761	20·7605	474	224676	21·7715
432	186624	20·7846	475	225625	21·7945
433	187489	20·8086	476	226576	21·8174
434	188356	20·8327	477	227529	21·8403
435	189225	20·8566	478	228484	21·8632
436	190096	20·8806	479	229441	21·8861
437	190969	20·9045	480	230400	21·9089
438	191844	20·9284	481	231361	21·9317
439	192721	20·9523	482	232324	21·9545
440	193600	20·9762	483	233289	21·9773
441	194481	21·0000	484	234256	22·0000
442	195364	21·0238	485	235225	22·0227
443	196249	21·0476	486	236196	22·0454
444	197136	21·0713	487	237169	22·0689
445	198025	21·0950	488	238144	22·0907
446	198916	21·1187	489	239121	22·1133
447	199809	21·1424	490	240100	22·1359
448	200704	21·1660	491	241081	22·1585
449	201601	21·1896	492	242064	22·1811
450	202500	21·2132	493	243049	22·2036
451	203401	21·2368	494	244036	22·2261
452	204304	21·2603	495	245025	22·2486
453	205209	21·2838	496	246016	22·2711
454	206116	21·3073	497	247009	22·2935
455	207025	21·3307	498	248004	22·3159
456	207936	21·3542	499	249001	22·3383
457	208849	21·3776	500	250000	22·3607
458	209764	21·4009	501	251001	22·3830
459	210681	21·4243	502	252004	22·4054
460	211600	21·4476	503	253009	22·4277
461	212521	21·4709	504	254016	22·4499
462	213444	21·4942	505	255025	22·4722
463	214369	21·5174	506	256036	22·4944
464	215296	21·5407	507	257049	22·5167
465	216225	21·5639	508	258064	22·5388
466	217156	21·5870	509	259081	22·5610
467	218089	21·6102	510	260100	22·5832
468	219024	21·6333	511	261121	22·6053
469	219961	21·6564	512	262144	22·6274
470	220900	21·6795	513	263169	22·6495
471	221841	21·7025	514	264196	22·6716
472	222784	21·7256	515	265225	22·6936
473	223729	21·7486	516	266256	22·7156

A TABLE OF THE SQUARES AND SQUARE ROOTS OF NUMBERS.—CONTINUED.

From 1 to 1000.

No.	Squares.	Square Roots.	No.	Squares.	Square Roots.
517	267289	22·7376	560	313600	23·6643
518	268324	22·7596	561	314721	23·6854
519	269361	22·7816	562	315844	23·7065
520	270400	22·8035	563	316969	23·7276
521	271441	22·8254	564	318096	23·7487
522	272484	22·8473	565	319225	23·7697
523	273529	22·8692	566	320356	23·7907
524	274576	22·8910	567	321489	23·8118
525	275625	22·9129	568	322624	23·8327
526	276676	22·9347	569	323761	23·8537
527	277729	22·9565	570	324900	23·8747
528	278784	22·9782	571	326041	23·8956
529	279841	23·0000	572	327184	23·9165
530	280900	23·0217	573	328329	23·9374
531	281961	23·0434	574	329476	23·9583
532	283024	23·0651	575	330625	23·9792
533	284089	23·0868	576	331776	24·0000
534	285156	23·1084	577	332929	24·0208
535	286225	23·1301	578	334084	24·0416
536	287296	23·1517	579	335241	24·0624
537	288369	23·1733	580	336400	24·0832
538	289444	23·1948	581	337561	24·1039
539	290521	23·2164	582	338724	24·1247
540	291600	23·2379	583	339889	24·1454
541	292681	23·2594	584	341056	24·1661
542	293764	23·2809	585	342225	24·1868
543	294849	23·3021	586	343396	24·2074
544	295936	23·3238	587	344569	24·2281
545	297025	23·3452	588	345744	24·2487
546	298116	23·3666	589	346921	24·2693
547	299209	23·3880	590	348100	24·2899
548	300304	23·4094	591	349281	24·3105
549	301401	23·4307	592	350464	24·3310
550	302500	23·4521	593	351649	24·3516
551	303601	23·4734	594	352836	24·3721
552	304704	23·4947	595	354025	24·3926
553	305809	23·5159	596	355216	24·4131
554	306916	23·5372	597	356409	24·4336
555	308025	23·5584	598	357604	24·4540
556	309136	23·5796	599	358801	24·4745
557	310249	23·6008	600	360000	24·4949
558	311364	23·6220	601	361201	24·5153
559	312481	23·6432	602	362404	24·5357

A TABLE OF THE SQUARES AND SQUARE ROOTS OF NUMBERS.—CONTINUED.

From 1 to 1000.

No.	Squares.	Square Roots.	No.	Squares.	Square Roots.
603	363609	24·5560	646	417316	25·4165
604	364816	24·5764	647	418609	25·4362
605	366025	24·5967	648	419904	25·4558
606	367236	24·6171	649	421201	25·4755
607	368449	24·6374	650	422500	25·4950
608	369664	24·6576	651	423801	25·5147
609	370881	24·6779	652	425104	25·5343
610	372100	24·6982	653	426409	25·5539
611	373321	24·7184	654	427716	25·5734
612	374544	24·7386	655	429025	25·5930
613	375769	24·7588	656	430336	25·6125
614	376996	24·7790	657	431649	25·6320
615	378225	24·7992	658	432964	25·6515
616	379456	24·8193	659	434281	25·6710
617	380689	24·8395	660	435600	25·6905
618	381924	24·8596	661	436921	25·7099
619	383161	24·8797	662	438244	25·7204
620	384400	24·8998	663	439569	25·7488
621	385641	24·9199	664	440896	25·7682
622	386884	24·9399	665	442225	25·7876
623	388129	24·9600	666	443556	25·8070
624	389376	24·9800	667	444889	25·8263
625	390625	25·0000	668	446224	25·8457
626	391876	25·0200	669	447561	25·8650
627	393129	25·0400	670	448900	25·8844
628	394384	25·0600	671	450241	25·9037
629	395641	25·0799	672	451584	25·9230
630	396900	25·0998	673	452929	25·9422
631	398161	25·1197	674	454276	25·9615
632	399424	25·1396	675	455625	25·9808
633	400689	25·1595	676	456976	26·0000
634	401956	25·1794	677	458329	26·0192
635	403225	25·1992	678	459684	26·0384
636	404496	25·2190	679	461041	26·0576
637	405769	25·2389	680	462400	26·0768
638	407044	25·2587	681	463761	26·0960
639	408321	25·2785	682	465124	26·1151
640	409600	25·2982	683	466489	26·1343
641	410881	25·3180	684	467856	26·1534
642	412164	25·3377	685	469225	26·1725
643	413449	25·3574	686	470596	26·1916
644	414736	25·3772	687	471969	26·2107
645	416025	25·3968	688	473344	26·2297

A TABLE OF THE SQUARES AND SQUARE ROOTS OF NUMBERS.—CONTINUED.

From 1 to 1000.

No.	Squares.	Square Roots.	No.	Squares.	Square Roots.
689	474721	26·2488	732	535824	27·0555
690	476100	26·2678	733	537289	27·0740
691	477481	26·2869	734	538756	27·0924
692	478864	26·3059	735	540225	27·1109
693	480249	26·3249	736	541696	27·1293
694	481636	26·3439	737	543169	27·1477
695	483025	26·3629	738	544644	27·1662
696	484416	26·3818	739	546121	27·1846
697	485809	26·4008	740	547600	27·2029
698	487204	26·4197	741	549081	27·2213
699	488601	26·4386	742	550564	27·2397
700	490000	26·4575	743	552049	27·2580
701	491401	26·4764	744	553536	27·2764
702	492804	26·4953	745	555025	27·2947
703	494209	26·5141	746	556516	27·3130
704	495616	26·5330	747	558009	27·3313
705	497025	26·5518	748	559504	27·3496
706	498436	26·5707	749	561001	27·3679
707	499849	26·5895	750	562500	27·3861
708	501264	26·6083	751	564001	27·4044
709	502681	26·6271	752	565504	27·4226
710	504100	26·6458	753	567009	27·4408
711	505521	26·6646	754	568516	27·4591
712	506944	26·6833	755	570025	27·4773
713	508369	26·7021	756	571536	27·4955
714	509796	26·7208	757	573049	27·5136
715	511225	26·7395	758	574564	27·5318
716	512656	26·7582	759	576081	27·5500
717	514089	26·7769	760	577600	27·5681
718	515524	26·7955	761	579121	27·5862
719	516961	26·8142	762	580644	27·6043
720	518400	26·8328	763	582169	27·6225
721	519841	26·8514	764	583696	27·6405
722	521284	26·8701	765	585225	27·6586
723	522729	26·8887	766	586756	27·6767
724	524176	26·9072	767	588289	27·6948
725	525625	26·9258	768	589824	27·7128
726	527076	26·9444	769	591361	27·7308
727	528529	26·9629	770	592900	27·7489
728	529984	26·9815	771	594441	27·7669
729	531441	27·0000	772	595984	27·7849
730	532900	27·0185	773	597529	27·8029
731	534361	27·0370	774	599076	27·8209

A TABLE OF THE SQUARES AND SQUARE ROOTS OF NUMBERS.—CONTINUED.

From 1 to 1000.

No.	Squares.	Square Roots.	No.	Squares.	Square Roots.
775	600625	27·8388	818	669124	28·6007
776	602176	27·8568	819	670761	28·6182
777	603729	27·8747	820	672400	28·6356
778	605284	27·8926	821	674041	28·6531
779	606841	27·9106	822	675684	28·6705
780	608400	27·9285	823	677329	28·6880
781	609961	27·9464	824	678976	28·7054
782	611524	27·9643	825	680625	28·7228
783	613089	27·9821	826	682276	28·7402
784	614656	28·0000	827	683929	28·7576
785	616225	28·0179	828	685584	28·7750
786	617796	28·0357	829	687241	28·7924
787	619369	28·0535	830	688900	28·8097
788	620944	28·0713	831	690561	28·8271
789	622521	28·0891	832	692224	28·8444
790	624100	28·1069	833	693889	28·8617
791	625681	28·1247	834	695556	28·8791
792	627264	28·1425	835	697225	28·8964
793	628849	28·1603	836	698896	28·9137
794	630436	28·1780	837	700569	28·9310
795	632025	28·1957	838	702244	28·9482
796	633616	28·2135	839	703921	28·9655
797	635209	28·2312	840	705600	28·9828
798	636804	28·2489	841	707281	29·0000
799	638401	28·2666	842	708964	29·0172
800	640000	28·2843	843	710649	29·0345
801	641601	28·3019	844	712336	29·0517
802	643204	28·3196	845	714025	29·0689
803	644809	28·3373	846	715716	29·0861
804	646416	28·3549	847	717409	29·1033
805	648025	28·3726	848	719104	29·1204
806	649636	28·3901	849	720801	29·1376
807	651249	28·4077	850	722500	29·1548
808	652864	28·4253	851	724201	29·1719
809	654481	28·4429	852	725904	29·1890
810	656100	28·4605	853	727609	29·2062
811	657721	28·4781	854	729316	29·2233
812	659344	28·4956	855	731025	29·2404
813	660969	28·5132	856	732736	29·2575
814	662596	28·5307	857	734449	29·2746
815	664225	28·5482	858	736164	29·2916
816	665856	28·5657	859	737881	29·3087
817	667489	28·5832	860	739600	29·3258

A TABLE OF THE SQUARES AND SQUARE ROOTS OF NUMBERS.—CONTINUED.

From 1 to 1000.

No.	Squares.	Square Roots.	No.	Squares.	Square Roots.
861	741321	29·3428	904	817216	30·0666
862	743044	29·3598	905	819025	30·0832
863	744769	29·3769	906	820836	30·0998
864	746496	29·3939	907	822649	30·1164
865	748225	29·4109	908	824464	30·1330
866	749956	29·4279	909	826281	30·1496
867	751689	29·4449	910	828100	30·1662
868	753424	29·4618	911	829921	30·1828
869	755161	29·4788	912	831744	30·1993
870	756900	29·4958	913	833569	30·2159
871	758641	29·5127	914	835396	30·2324
872	760384	29·5296	915	837225	30·2490
873	762129	29·5466	916	839056	30·2655
874	763876	29·5635	917	840889	30·2820
875	765625	29·5804	918	842724	30·2985
876	767376	29·5973	919	844561	30·3150
877	769129	29·6142	920	846400	30·3315
878	770884	29·6311	921	848241	30·3480
879	772641	29·6479	922	850084	30·3645
880	774400	29·6648	923	851929	30·3809
881	776161	29·6816	924	853776	30·3974
882	777924	29·6985	925	855625	30·4138
883	779689	29·7153	926	857476	30·4302
884	781456	29·7321	927	859329	30·4467
885	783225	29·7489	928	861184	30·4631
886	784996	29·7658	929	863041	30·4795
887	786769	29·7825	930	864900	30·4959
888	788544	29·7993	931	866761	30·5123
889	790321	29·8161	932	868624	30·5287
890	792100	29·8329	933	870489	30·5450
891	793881	29·8496	934	872356	30·5614
892	795664	29·8664	935	874225	30·5778
893	797449	29·8831	936	876096	30·5941
894	799236	29·8998	937	877969	30·6105
895	801025	29·9166	938	879844	30·6268
896	802816	29·9333	939	881721	30·6431
897	804609	29·9500	940	883600	30·6594
898	806404	29·9666	941	885481	30·6757
999	808201	29·9833	942	887364	30·6920
900	810000	30·0000	943	889249	30·7083
901	811801	30·0167	944	891136	30·7246
902	813604	30·0333	945	893025	30·7409
903	815409	30·0500	946	894916	30·7571

A TABLE OF THE SQUARES AND SQUARE ROOTS OF NUMBERS.—CONTINUED.

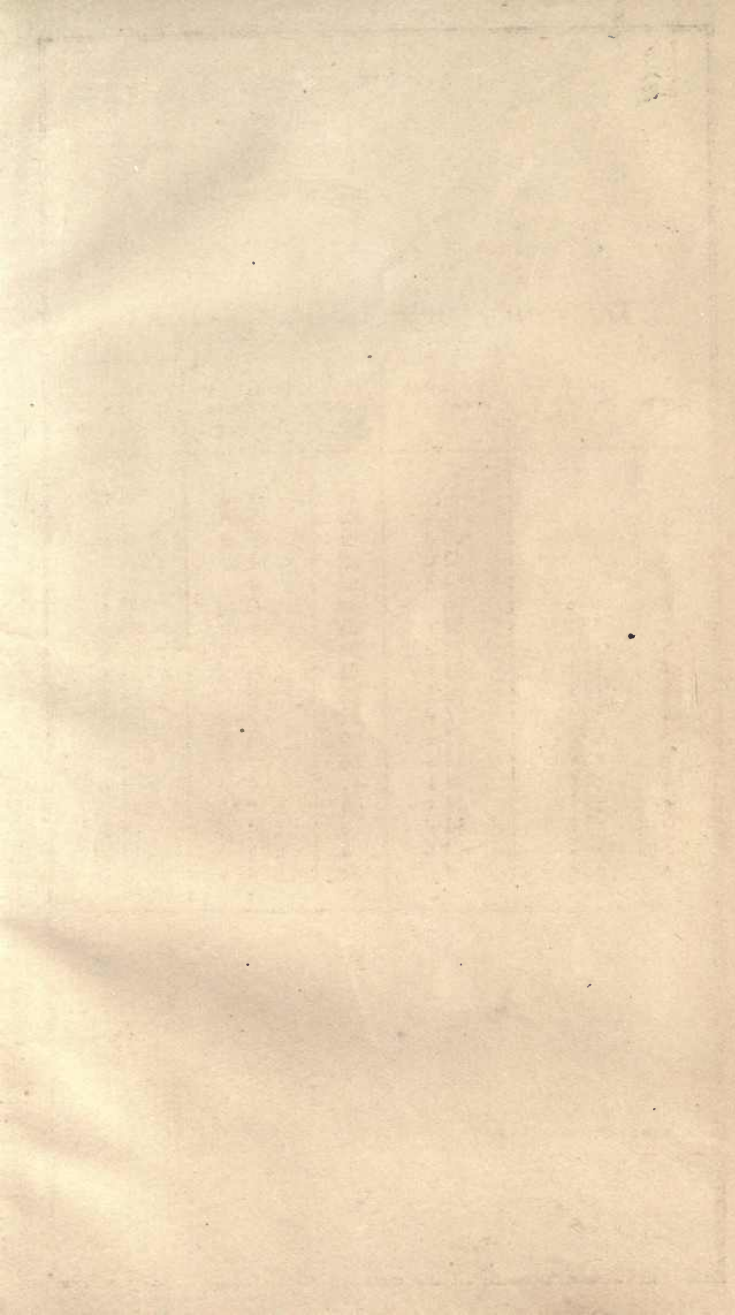
From 1 to 1000.

No.	Squares.	Square Roots.	No.	Squares.	Square Roots.
947	896809	30·7734	974	948676	31·2090
948	898704	30·7896	975	950625	31·2250
949	900601	30·8058	976	952576	31·2410
950	902500	30·8221	977	954529	31·2570
951	904401	30·8383	978	956484	31·2730
952	906304	30·8545	979	958441	31·2890
953	908209	30·8707	980	960400	31·3050
954	910116	30·8869	981	962361	31·3209
955	912025	30·9031	982	964324	31·3369
956	913936	30·9192	983	966289	31·3528
957	915849	30·9354	984	968256	31·3688
958	917764	30·9516	985	970225	31·3847
959	919681	30·9677	986	972196	31·4006
960	921600	30·9839	987	974169	31·4166
961	923521	31·0000	988	976144	31·4325
962	925444	31·0161	989	978121	31·4484
963	927369	31·0322	990	980100	31·4643
964	929296	31·0483	991	982081	31·4802
965	931225	31·0644	992	984064	31·4960
966	933156	31·0805	993	986049	31·5119
967	935089	31·0966	994	988036	31·5278
968	937024	31·1127	995	990025	31·5436
969	938961	31·1288	996	992016	31·5595
970	940900	31·1448	997	994009	31·5753
971	942841	31·1609	998	996004	31·5911
972	944784	31·1769	999	998001	31·6070
973	946729	31·1929	1000	1000000	31·6228

TABLE OF SLOPES, &c.—For TOPOGRAPHY.

Degrees.	Vertical Rise in 100 feet horizontal.	Horizontal Distance to a rise of 10 feet.	Degrees.	Vertical Rise in 100 feet horizontal.	Horizontal Distance to a rise of 10 feet.
°			°		
1	1.75	572.9	19	34.43	29.0
2	3.49	286.4	20	36.40	27.5
3	5.24	190.8	21	38.40	26.0
4	6.99	143.0	22	40.40	24.7
5	8.75	114.3	23	42.45	23.5
6	10.51	95.1	24	44.52	22.4
7	12.28	81.4	25	46.63	21.4
8	14.05	71.2	26	48.77	20.5
9	15.83	63.1	27	50.95	19.6
10	17.63	56.7	28	53.17	18.8
11	19.44	51.4	29	55.43	18.0
12	21.25	47.0	30	57.73	17.3
13	23.09	43.3	35	70.02	14.2
14	24.93	40.1	40	83.91	11.9
15	26.79	37.3	45	100.00	10.0
16	28.67	34.9	50	119.17	8.4
17	30.57	32.7	55	142.81	7.0
18	32.49	30.7	60	173.20	5.7





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